MEAT & LIVESTOCK AUSTRALIA

On farm

# Safe Use of Manure and Effluent – A Technical Users Manual

**Project number FLOT.402**

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Feedlots

# 1 INTRODUCTION

Manure or "muck" is one of the world's oldest and most reliable commodities. It can be used to prevent land degradation and improve rural property returns and values. Effluent or waste water is a valuable source of water and nutrient. At times it requires careful management if it contains appreciable levels of 'salt'. Many farmers and graziers overlook the potential benefits of application of manure and effluent to their crops and pastures because the use and convenience of inorganic fertilisers has become common place.

Intensive livestock industries including feedlots, piggeries, and poultry systems generate large quantities of manure. The gross capacity of these industries are about 900,000 cattle (1,500,000 head/yr), 307,000 sows (3,100,000 pigs/yr) and an estimated 17 million hens. These industries are important to Australian agriculture as they add significantly to the value of meat products. Together they generate over 4,000,000 tonnes of manure and many gigalitres of effluent.

Feedlots consume significant amounts of quality feed grains. It is for this reason that most feedlots (and other intensive livestock industries) are located within grain growing regions (see Figure 1). Feedlots generate about 1.1 to 1.5 million tonnes of manure and 6,200 ML of effluent each year.

Critical issues for the reuse of these by-products are;

- most of the manure from intense animal industries are applied to land surrounding the facility but haulage costs limit the radius of use.
- effluent use is typically restricted to the feedlot farm.
- the quality of the manure and effluent and its over application to land which causes nutrient imbalances and excess levels of salts and especially sodium[1].
- defining economically viable and environmentally safe reuse practices

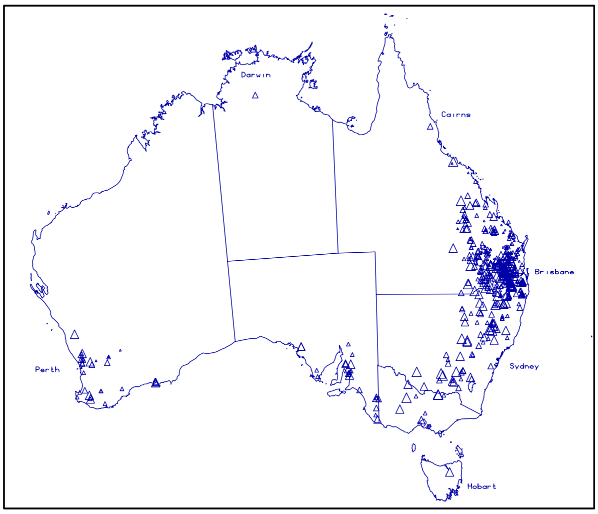



**Figure 1** Location of Feedlots throughout Australia.

The Meat and Livestock Australia funded project FLOT 202 "Safe Utilisation of Feedlot Manure and Effluent" has studied the effects of manure and effluent on soils and crop production. It has identified key land and manure application management practices that are needed to minimise nutrient loss to the environment. Indeed, safe use of manure can achieve a reduction in runoff and nutrient losses. It has redefined the value of manure and shown that manure is both undervalued and an important soil conditioning product needed to recover degraded land areas. This manual aims to highlight and clarify the issues critical for safe use of feedlot manure and effluent.

## 2 CHARACTERISTICS OF MANURE

The characteristics of manure vary across the different intensive livestock systems. Beef feedlot manure is different to that generated by a dairy, pig or a poultry system. Differences occur in the chemical composition of the manure and also the rate of mineralisation of the manure. Tabulated values for the physical and chemical characteristics of fresh manure are presented in Table 1. These data are indicative values only and are provided so that comparisons can be drawn across the manure types.

**Table 1.** Fresh Manure Production and Characteristics (Manure = Faeces + Urine)[2]. (Units expressed on a kg-wet basis per 1000kg live animal mass or as a % per kg of dry matter)

| | Animal Type # | | | |
|---|---|---|---|---|
| Parameter | Beef | Dairy | Pigs | Broiler |
| Total Manure (kg) | 58 | 86 | 84 | 85 |
| Urine (kg) | 18 | 26 | 39 | N/A. |
| Total Solids (kg) | 8.5 | 12 | 11 | 22 |
| Volatile Solids (kg) | 7.2 | 10 | 8.5 | 17 |
| Total Kjeldahl Nitrogen (%) | 4 | 3.75 | 4.73 | 5.0 |
| Ammonia Nitrogen (%) | 1 | 0.67 | 2.64 | 3.20[3] |
| Total Phosphorus (%) | 1.1 | 0.78 | 1.64 | 1.36 |
| (Available) Ortho-Phosphorus (%) | 0.35 | 0.51 | 1.09 | 1.1 [2] |
| Potassium (%) | 2.47 | 2.42 | 2.64 | 1.82 |
| Calcium (%) | 1.65 | 1.33 | 3.0 | 1.86 |
| Magnesium (%) | 0.58 | 0.59 | 0.64 | 0.68 |
| Sodium (%) | 0.35 | 0.43 | 0.61 | 0.68 |
| C:N ratio (approx.)[2] | 10 | 12 | 7 | 8 |

# Differences in species exist and may vary with age, feed ration, breed and handling

These data show that only 25% of the nitrogen (N) and 30% of the phosphorus (P) in fresh beef manure is in the available form and the remainder is in a complexed organic form. The availability of N and P in pig manure is higher than that of beef manure and the availability of N and P is greatest in poultry manure. However, the carbon content of the beef and dairy manure is greater than that of pig and poultry manure because of the considerable amount of fibrous material in the feedstuffs.

Different ration composition, intake levels and stresses affect the amount of nutrient retained in the body and voided in the fresh manure. The effects of weather, storage, and post-harvest treatment alter the “as excreted” values. Manure from feedlots can vary greatly in quality and much of the variance can be attributed to changes in commodity type and quality used in the formulation of the diet and the methods used in the collection and storage of the pen manure. The intake of minerals through drinking water can also have a significant effect on manure quality and especially deleterious ‘salts’ such as sodium (Na). On the other hand broiler shed manure has less variability because of the high degree of standardization in confinement systems, ration formulations and production systems.

Each type of manure has a fertilizer value and potential positive effect on soils through the addition of organic matter to the soil. However, the relative worth of manure can be considered in terms of the quantity and rate of supply of plant macro-nutrient (e.g., N, P, Potassium (K), and Sulphur (S)) and the amount of complex Carbon (C) added to the soil.

When manure is added to the soil the amount of nutrient that can be supplied to the plant is affected by two factors;

- the amount of nutrient in the manure already in the available form (i.e. inorganic compounds such as nitrate and orthophosphate), and,
- the rate of mineralisation once it is added to the soil (i.e. the rate that complex organic molecules are broken down into the simple inorganic compounds).

Microbes break down the organic compounds. The rate of biological conversion of the organic matter will influence the supply of nutrient over time and this rate of conversion is called the decay rate and is typically expressed as a percentage change from the original amount added to the soil over time.

The rate of nitrogen mineralisation depends on,

- the concentration of total nitrogen in the manure,
- the amount of urea or uric acid form (organic nitrogen in the urine fraction),
- temperature and moisture conditions,
- amount of organic N (or N that can be mineralised) already in the soil, and,
- the C:N ratio.

The type of nitrogen excreted is dependent upon the animal. Poultry excrete a high percentage of N as uric acid. Mammals excrete about half of their nitrogen in urine as urea and the rest in faeces as undigested organic matter and synthesized microbial cells. It is important to note that both uric acid and urea are quite unstable and are rapidly decomposed by microorganisms. This N is converted to ammonium. The N in faeces is released far more slowly and at a rate dictated by the activity of microbes.

The complex organic molecules in manure are a food and energy source for microbes. Microbes typically require a source of carbon and nitrogen for their metabolism. Therefore, the mineralisation rate is affected by the C:N ratio found in the manure As the data in Table 1 show the C:N ratio of manures is less than 20:1 which is considered to be an ideal balance between the two elements. At high C:N ratios (e.g. 100:1 which is found in timber products) the limited amount of N is taken up by the microbes and immobilized as organic N. This N is only released once the quantity of C is significantly reduced. On the other hand where the C:N ration is low (e.g. less than 15:1) a significant N loss will occur until the ration increases. Nitrogen is lost to the atmosphere when microbes convert nitrate to nitrous oxide or nitrogen gas.

Composting of feedlot manure can remove much of the variability found in the raw product. However, this comes at the expense of a significant reduction in both C and N as the microbes break down the complex organic matter. While this stabilizes the C:N ratio a significant amount of ammonia nitrogen is lost to the atmosphere. Composting generally results in increased concentrations of other nutrients such as P, K, Ca, and S.

The manure types do have different fertilizer and soil ameliorant values because of their chemical attributes and their subsequent effects on soil chemistry and microbial activity. Poultry manure has a comparatively large amount of available nutrient, low C:N ration and as a result its addition to soils results in a large amount of nutrient being available for plant uptake in year one and only a limited amount of nutrient being supplied in latter years through the break down of complex forms. It only contributes a small amount of C the soil.

The dynamics of the addition of beef cattle manure to the soil are quite different. Less of the added nutrient is available in year one but there is a subsequent and steady release in later years two, three and four through the decomposition of the complex organic matter. Importantly, the addition of this organic matter has a far greater and sustained positive effect on the soil than that of pig and poultry manure because it remains as a long term food source for microbes and soil binding agent. In the latter case, the improvement in soil structure attributed to the added organic carbon or soil organic matter (SOM) can increase infiltration and thus reduce runoff, increase soil water storage and thus increase the potential for plant productivity.

Manure contains many other nutrients apart from nitrogen and it is a valuable source of fertiliser. The ‘equivalent’ inorganic fertiliser value of feedlot manure is about $45-65 per tonne on a dry basis and $30-50 per tonne on a wet basis. This value is based on the gross amount of nutrient that it contains. While some nutrient becomes available through microbial decomposition some nutrient is also lost to the environment or is bound with soil compounds in forms not recoverable by plants. The latter processes occur with all inorganic fertilisers.

While increased nutrient availability can be obtained through inorganic fertiliser applications, it is obvious that a significant factor in obtaining higher crop yields through the use of organic fertilisers (manure) is through increased levels of SOM. The SOM can make up more than 50% of the soil cation exchange capacity, which means it is a key mechanism of holding water and nutrient (see Section 5.2).

Manure directly from a pen has different attributes to stockpiled manure. Stockpiling of manure usually results in reduced moisture and increased nutrient concentrations. Table 2 shows the amount of nutrient in 1 tonne of manure in a dry and wet basis. Stockpiled manure is a valuable source of fertiliser. The equivalent fertiliser value of manure is about $55 per tonne on a dry basis and $39 per tonne on a wet basis.

**Table 2.** Average Chemical Analysis of Beef Cattle Feedlot Manure[4].

| Element | Range (% DM) | Average (% DM) | kg / T (dry manure) | kg / T (wet manure) |
|---|---|---|---|---|
| N | 1.16-1.96 | 2.04 | 20.4 | 14.3 |
| P | 0.74-1.96 | 0.81 | 8.1 | 5.7 |
| K | 0.9-2.82 | 2.20 | 22.0 | 15.4 |
| Ca | 0.81-1.75 | 1.63 | 16.3 | 11.4 |
| Mg | 0.32-0.66 | 0.90 | 9.0 | 6.3 |
| Na | 0.29-1.43 | 0.57 | 5.7 | 4 |
| S | | 0.42 | 4.2 | 2.9 |
| Cl | | 1.24 | 12.4 | 8.7 |
| Fe | 0.09-0.55 | 0.21 | 2.1 | 1.5 |
| Zn | 0.005-0.012 | 0.0154 | 0.154 | 0.108 |

Most information on manure application rates has been based on research in the United States. Typically, the availability of N has been the major determinant in the calculation of manure application rates. The rate of manure decay, and hence release of nitrogen, is variable and dependant on the nutrient, particularly nitrogen content and the age of the manure. In the United States the residual effects of decomposed manures on inorganic N fertiliser uptake by maize showed that after three years of maize production without N fertiliser the N mineralisation potential of the treated soil was reduced to that of the original soil[5]. Apparent fertiliser recoveries of N and P are low for this reason and also due to losses of N as $NH_4$ volatilised from the surface spread manure[6,7]. The mineralisation rate of two manures with different nitrogen contents are presented in Figure 2[8]. Clearly, the nitrogen availability during year one varies greatly and rages from 30% for well aged manure to over 60% for fresh manure. These data are likely to be different in Australian conditions.

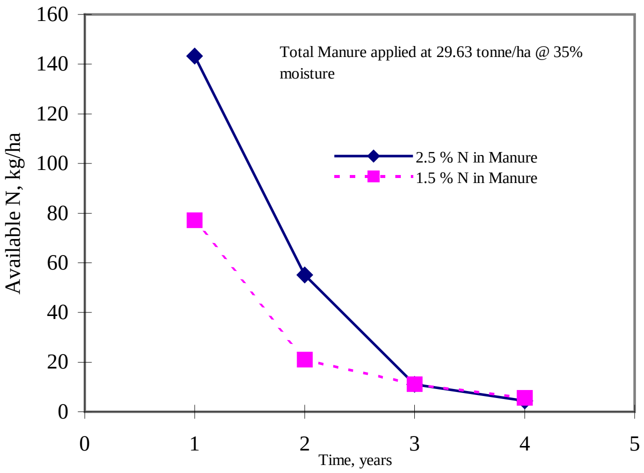



**Figure 2** Mineralisation Rates of Nitrogen in two manures (Pratt et al., 1973)

Recent studies in Australia have been used mass balance calculations to determine "sustainable" manure application rates (see Section 4). They show that in many cases P or K should be the limiting element. One of the major unknowns in estimating safe application rates of manure using elements other than N is their mineralisation rates. It is clear that the mineralisation rates of P and K and other elements in feedlot manure has not been widely studied nor published. Recent research indicates that the long term availability of P and K in manure is about equal to that of commercial fertilisers.

Manure can contain some deleterious salts. Of primary concern is sodium (Na). Excessive soil Na accumulation is likely with continued heavy application of high sodium content manure. However, this is unlikely to be a problem with typical application rates of average sodium content manure. The use of gypsum and lime can be used to offset imbalances between Calcium (Ca) and Na if the need arises.

## - IMPORTANT -
## NOTES, HINTS AND TIPS

- Beef cattle feedlot manure has a sustained release of nutrient and has a greater soil conditioning value than other manures.
- Raw manure is variable in quality and price, ranging from $3 - $20 per tonne (wet).
- Less salt in rations and drinking water means less salt in manure.
- Composted manure is higher quality product and value adds to the product with prices being $10 - $30 per tonne (wet). It has a stable C:N ratio and more P, K and S than raw manure.

## 3 CHARACTERISTICS OF EFFLUENT

Effluent contains nutrients and water that are valuable to plant production. However many of the soluble salts excreted by animals readily pass into rainfall-runoff, either by being washed off the pen surface and/or dissolving in the flows. As a consequence, the chemical make up of fresh rainfall-runoff is typically characterised by the presence of entrained organic matter and a relative abundance of soluble ions such as nitrate, ortho-phosphate, sulphate, and the cations sodium and potassium.

The attributes of effluent discharged into a holding pond change markedly through time. The changes start occurring immediately, and are triggered by the rapid decomposition of the organic matter carried by the rainfall-runoff flows. Typically the decomposition process strips all oxygen from the water body and as a result, anaerobic decomposition processes take over. This may cause the pH of the water body to change markedly, and will cause both precipitation and disassociation of some compounds in the water body.

Over time the decomposition process will stabilise effluent and qualities may then remain reasonably static in the short term. A reduction in nitrogen and phosphorus content will occur as decomposition of complex organic molecules continues. Nitrogen is lost by volatilisation and phosphates are precipitated from the water in combination with elements such as aluminium, calcium and iron. Water is also lost from the water body through evaporation. If the effluent is stored for long periods of time, these processes will lead to increasing concentrations of sodium, and at times potassium, and a general reduction in most other plant macronutrients.

While plants require potassium in significant quantities they have almost no need for sodium. The addition of sodium to the soil in excessive quantities will lead to soil structural decline through sodicity (disproportionate levels of sodium in the soil), and potentially salinity problems. This will result in crop yield reductions.

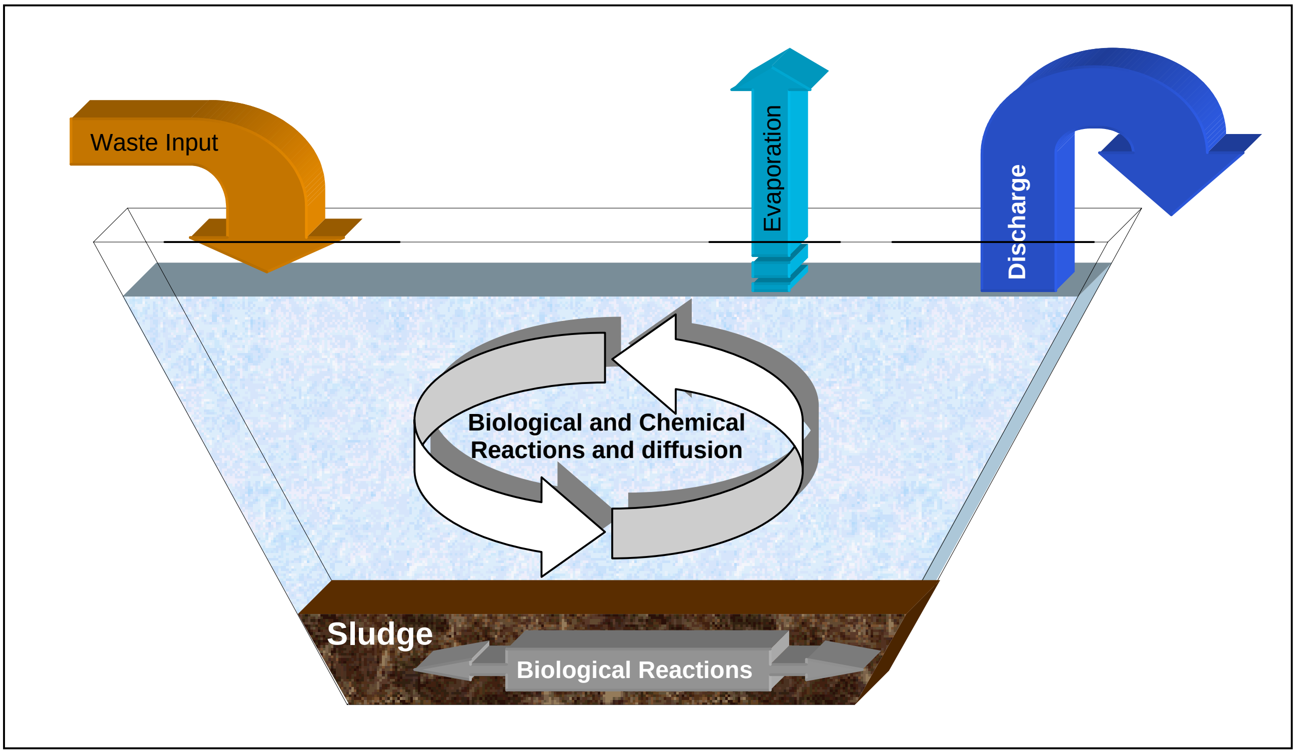



**Figure 3** General overview of biological activity in effluent treatment pond

The decomposition process in a pond also creates some very small weakly charged organic compounds that can remain dissolved in the effluent ('solutes' - see Section 5.4). Among these are minute phosphorus based organic compounds that can move through a soil when effluent is excessively applied. Interestingly, they can also be generated in a soil through incomplete decomposition of any organic matter. Over application of effluent can cause the loss of these compounds in seepage and thus the passage of nutrient into ground waters. The best means of managing this phenomenon is to ensure that deep drainage from the soil profile is managed and most importantly the soil structure remains aerated and biologically active. This promotes complete decomposition of organic compounds and the generation of plant available ions. The addition of excessive amounts of sodium actively works against this objective (see Section 7).

Effluent is a high strength waste as illustrated by the observed levels of total N, P and K from Australia and the United States (Table 3).

**Table 3.** Average Chemical Analysis of Beef Cattle Feedlot Effluent

| Component (Total) (mg/L) | US Sweeten (1989) | Australia | kg per 1 ML (Australian data) |
|---|---|---|---|
| N | 720.55 (286 - 1155) | 190 (12-396) | 190 |
| P | 103.76 (26-440) | 50 (3-142) | 50 |
| K | 2370 (985-9102) | 1515 (28-6003) | 1515 |
| Cl | - | 420 | 420 |

The net worth of effluent is therefore directly influenced by:

- its chemical make up and therefore its fertiliser value;
- the equivalent value of irrigation water it contains;
- the cost of clean water needed to dilute it and sustain crop growth when there is no effluent available; and
- the amount of soil additives required for maintenance of soil health.

Therefore, while effluent may have a gross worth of $250/ML the need for clean irrigation water and additives, such as gypsum or lime, can reduce its overall value.

**- IMPORTANT -**
**NOTES, HINTS AND TIPS**

- Longterm storage of effluent in ponds results in an increased concentration of 'salts' and loss of nutrients in the water and less water for irrigation: Ultimately there is a reduction in the waste waters value.
- Some effluent can be saline and it should not be applied to seedlings.
- Reducing 'salt' in rations and drinking water (especially sodium and potassium) will minimise 'salt' levels in effluent.

# 4 THE SOIL – PLANT SYSTEM AND SOIL NUTRIENT MANAGEMENT

There are six major elements that are required for plant growth. Carbon, Oxygen (O), Hydrogen, Nitrogen, Phosphorus and Sulphur form 95% of the mass of all plants, animals and micro-organisms. Soil organic matter is the major supplier of P and S and is essentially the sole source of N. C, O, and H are primarily obtained from $CO_2$ and $O_2$ in the atmosphere and $H_2O$ from the soil solution. Water is the main agent in moving solutes in the soil profile and an important one in conveying them to root surfaces[9]. It is now widely accepted that under given growth conditions roots uptake of a solute is related to its concentration in the soil solution and the extent that it is buffered by the soil. Therefore, soil fertility and health must be maintained to feed the plant water, nutrient and salts.

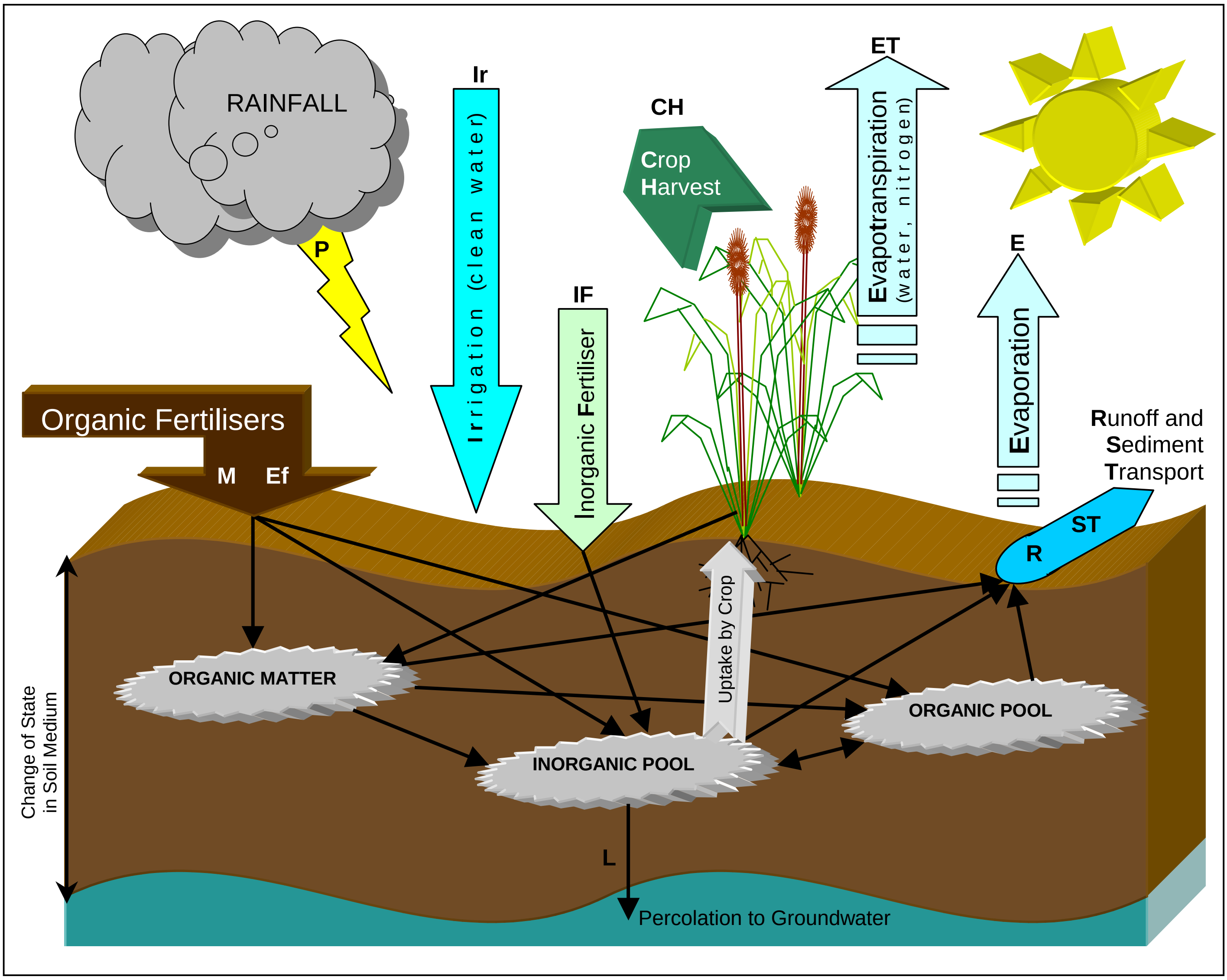



**Figure 4** Plant - Soil Dynamics

A ‘mass balance’ approach to defining safe application rates to a waste reuse area aims to balance the inputs of water, nutrient, and salt into the land area supporting the soil-plant-atmosphere system, with the removal of nutrient and salt by a crop, assimilation of nutrient and salt by the soil, and the losses by gas, runoff, and leaching.

The mass balance for the soil-plant system shown in Figure 3 can be described by the equation below;

$$\Delta S = P + M + Ef + Ir + IF - CH - R - ST - L - ET - E$$

*where,*

$\Delta S$ = net change of state in the soil.
$P$ = precipitation (input)
$M$ = manure application (input)
$Ef$ = effluent application (input)
$Ir$ = clean water irrigation (input)
$IF$ = inorganic fertiliser application (input)
$CH$ = crop harvest (output)
$R$ = rainfall-runoff (output)
$ST$ = sediment transport (output)
$L$ = percolation (output)
$ET$ = evapotranspiration (output)
$E$ = evaporation (output)

Each of the above variables represents a mass of water, a nutrient or a salt. At times, a variable can be excluded from the equation because it has no significant bearing on the mass balance of a particular element. For example little salt is removed during soil water evaporation, and in a mass balance of salt, this loss by evaporation can be excluded.

The mass balance approach has been theoretically applied to abattoir, piggery and feedlots and their waste utilisation areas[10,11,12]. The use of the calculation including a “lifespan” for land disposal areas has also been applied to mass balance theory. In this case, the soil is considered to act as a finite sink for nutrient accumulation and when this capacity is exceeded (that is it becomes saturated), the area cannot be further used as the excess nutrient will migrate from the site. The time taken to saturate the soil defines the “lifespan”. In the case of P, The ‘lifespan’ of a P sorption isotherm for a full soil profile is used to define the size of the sink. It is equal to the sink divided by the net annual application of P. However, reliance on the soil to act as a sink for phosphorus is fraught with problems and may result in increased and significant environmental impact (see Section 0). This is not recommended.

Leaching, rainfall-runoff, and soil erosion are key vectors for the loss of nutrient and salt from the system. However, few data exist on these losses from land areas receiving feedlot wastes. Moreover, few acceptable limits have been defined for the losses or the build up of nutrient in a soil. Most criteria that have been described are directly related to soils that have exhibited deficiencies. Few data exist on the levels that are considered to be ‘high’ or luxuriant in a soil (see section 5.5.1).

It is suggested that the prudent option for soil nutrient management is one of allowing levels of plant macro nutrients to build to a level where plant production is not limited and excess nutrient leakage is not excessive. This means that once a soil nutrient level has reached a level above ‘adequacy’ a balance should be struck between application rate and removal rate. This prevents the abuse of a soil through overloading that inevitably limits its life (and the life of a business), yet allows for maximum agricultural production. This approach will also cause the least environmental harm. The cation balance must also remain reasonably balanced with neither salinisation nor soil sodicity occurring (see section 5.4).

In summary, it is now considered that safe or 'sustainable' waste utilisation is achieved when:

- most nutrients are captured by plant growth,
- soil nutrient stores are above the level needed to meet plant demands,
- soil nutrient levels are not at levels above 'break out' values where nutrients bleed excessively into the environment (these levels are, in most cases, below saturated concentrations),
- soil nutrient levels are in reasonable balance such that toxicities are not created by oversupply or deficits, and
- some leaching of salts occurs but at levels that do not degrade existing ground waters.

**- IMPORTANT -**
**NOTES, HINTS AND TIPS**

- Soils loose excess nutrient at increased rates well before they become "saturated"
- So don't use a "lifespan" method for determining application rates because you will loose nutrient (and therefore $$) and damage the environment well before the lifespan is reached
- Farmers should aim to match gross nutrient application rates with crop removal rates for a 3 year program

## 5 SOILS AIN'T JUST SOILS

### 5.1 Introduction

Australia is an arid continent with poor soils and a scarcity of water. Australian soils are low in organic matter (SOM) and many nutrients including phosphorus (P) and sulphur (S). Continuous farming with low residue return rates and cultivation reduces SOM levels. Therefore, SOM levels in most Australian soils have been in steady decline for decades, if not centuries. The low SOM levels in many Australian soils reduces their health and resilience against nutrient loss by leaching and erosion of soil. Simply, the soil-plant system becomes 'leaky' and less productive. Because the soil is 'leaky' more nutrient and water is lost to the environment. This is the primary reason why nutrient losses into watercourses have increased and water tables have risen. These processes cause degradation of Australia's streams and land. Manure is a source of organic matter that can be applied to soils to improve the health and nutritional status.

A number of different physiochemical and biological processes occur in soil and can reduce constituent concentrations or immobilise pollutants to reduce potential risks[13]. These include microbial processes associated with rhizosphere, biological oxidation and mineralisation, nitrification and denitrification, immobilisation by adsorption on ion exchange sites, binding onto organic matter, precipitation in to insoluble compounds, complexation, chelation and incorporation into lattice structures. The effectiveness of the soil as a filter depends on the extent of these mechanisms, which in turn, depends on soil characteristics such as texture, porosity, organic matter content, cation exchange capacity, redox potential and pH (different soils have different capacities for nutrients and pollutant reduction) as well as climatic considerations such as temperature and rainfall. The processes need to be well understood for effective utilisation of manure and effluent.

Removal processes for raised nitrogen in soil include immobilisation of organic nitrogen, and adsorption of ammonia, the first breakdown product of proteins, by soil particles as ammonium ion. Nitrate ions, however, are extremely mobile in soil. If not taken up by plants or lost to the atmosphere as denitrification products, nitrate will be leached and contaminate groundwater. Successful denitrification requires a nitrate supply, a supply of readily available organic carbon and anoxic conditions but also warm temperatures.

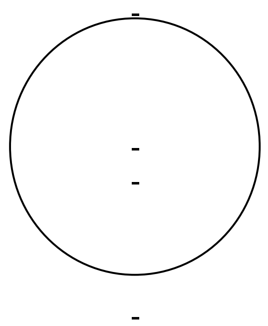
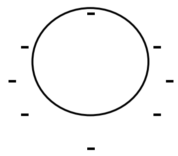
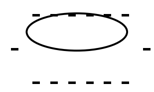
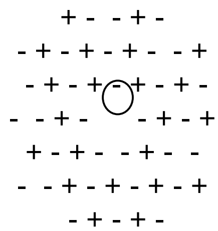
## 5.2 Components of a Soil

The soil matrix is structured of various sized particles. The quantities of sands, silts, clays and humus found in a soil is directly influenced by the parent materials from which the particles were derived, weather and climate and mans influences. The surfaces of these particles contain charges. In the case of sands, silts and clays the charge sites or exchange sites are predominantly negative. The amount of charge also various between the different sized particles. Figure 5 shows that the sand particles have the least amount of charge while the clay particles the most. The type of clay particle also affects the amount of charge. Expansive clays such as black earths found on the Breza Plains, New South Wales and Darling Downs, Queensland have a large component of montmorillinite clay particles. These clays have the most exchange site of all clay types.

The charged sites on soil particles attract and hold oppositely charged particles. Of particular importance are the cations. They have positive charges and are therefore held on the exchange sites. The gross amount of exchange sites is indicated by the measurement of the soil “cation exchange capacity” which is related to the gross amount of cations (Calcium (Ca), Magnesium (Mg), Potassium (K), Sodium (Na) and Aluminium (Al)) held in exchangeable forms.

The decomposition of organic matter produces humus. The humus is an amorphous compound, has a large surface area, is highly charged (though it has a generally net negative balance) and has a strong tendency to form complexes with micronutrient cations. The humus fraction of the soil organic matter contributes most to cation exchange capacity, the cation exchange sites of which occur on certain reactive groups. The number of such groups tends to increase as the organic matter decomposes so the cation exchange capacity (CEC) of the organic fraction may change over time. The soil organic matter can contribute up to half of the total soil cation exchange capacity and should not be discounted as a significant supplier of plant cations.

**Figure 5** Components of a Soil

| Sand | Silt | Clay | Humus |
|---|---|---|---|
| Large Particle Size | Medium Particle Size | Small Particle Size | Small Particle Size |
| Nil – Low Charge | Low – Medium Charge | Medium – High Charge | High to extreme Charge |
|  |  |  |  |

The chemistry of a soil is made up of three components. The readily available component is reasonably mobile and will move in water passing through the soil lattice. The exchangeable component includes the available component and also the ions that are attached to 'exchange' sites on organic and clay particles. The exchangeable component gives a good indication of the proportion of the pool that is accessible to plants. Indeed most soil chemistry tests for exchangeable ions attempt to mimic the interaction between the plant and the soil. An example of this is the use of DTPA for the extraction of cations from soil. It is a chelating agent that mimics the removal of ions from the exchange sites in a similar manner to roots. The total component includes the available and exchangeable ions and also the elements that are tightly bound in organic matter, and inorganic compounds.

**- IMPORTANT -**
**NOTES, HINTS AND TIPS**

- Clay particles in soil have a lot of negative charge.
- SOM has even more charges than the most highly charged clays, with some positive and a lot of negative charges.
- CEC provides a relative indication of a soils number of charged sites.
- The amount of charge in soil affects its ability to hold onto nutrients and water that plants can use.
- It takes longer to correct soil problems in a clay than in a sandy loam.

### 5.3 Role of SOM

Soil organic matter (SOM) is of interest for three main reasons: (i) it is the source of energy for biological activity, (ii) its effect on physical properties of the soil, and (iii) the nutrients supplied to plants following its decomposition[14]. Soil organic matter consists of two components; the original plant material and that originally modified from plant tissues and its partially decomposed derivatives and, the humus. The original material consists of mostly undecomposed plant matter (eg. roots, tops of plants and manures). The main building block of organic matter is carbon. In addition to carbon, SOM is composed of H, O, P, N, and S.

Humus is a gelatinous substance derived from the decomposition process. This, together with some sugars is the glue that helps hold together mineral particles to form aggregates whilst colouring the soil black or brown[15]. Its capacity to hold water and nutrient ions is far greater than that of clay. Humus therefore adds greatly to a soils capacity to promote plant growth. The influence of organic matter goes well beyond its ability to supply plant nutrients. Organic matter is transient in the soil and it must be renewed constantly through the return of crop residues, or the addition of sludges, manures and/or effluent.

Increased levels of organic matter in the soil profile benefits its physical, chemical and micro-biological properties and should be maintained at as high a level as possible in order to sustain the productivity and health of the soil[16]. Microorganisms and the products of organic matter decomposition help soil particles form larger soil aggregates[17]. Organic matter acts as a “granulator” in the soil and is largely responsible for the loose friable nature of productive soils. Larger aggregates result in larger soil pores that permit the rapid transfer of oxygen and water into the root zone. Research has shown positive correlations directly between soil microbe populations and crop yields.

### 5.4 ‘Salts’, Solutes, Sodicity and Salinity

Solutes and salts are not different chemical compounds *per se.* While they are not mutually exclusive groupings, it is important to define some differences. A solute can be loosely described as any dissolved substance, whereas a ‘salt’ is a compound of basic and acid radicals where the whole or part of its hydrogen is replaced by a metal or metal-like radicals. An example of a solute is a soluble protein or a sugar, such as glucose or a simple compound like ammonium phosphate. Salts include common table salt (sodium chloride NaCl), which dissociates in water as sodium ($Na^+$) and chloride ($Cl^-$) ions. A significant difference between the behaviour of solutes and salts is their effect upon water chemistry. Sugar, for example is soluble in water but does so without altering the electrical conductivity (EC) of the liquid, however common salt (NaCl) causes a large increase in EC for a relatively small addition. Salts are, in essence, a subset of solute compounds.

Excessive accumulation of nutrients such as phosphorus (P) in a soil may result in a bleeding of both ionic and organic P (P salts and solutes respectively) to the environment. It has been found that in intensive dairy pasture systems on sandy loam soils a significant amount of P leaving the soil in leachate was as poorly charged organic P compounds (solutes) rather than the orthophosphate ion or P ‘salt’[18]. However when soluble P compounds are added to soils, much of the P is rendered insoluble within hours through processes of adsorption and precipitation, with the former being the most important[19].

Nitrogen, whether sourced from wastewater or produced naturally from symbiotic relationships of bacteria and plants or soil microorganisms, behaves differently to either phosphorus, potassium or sodium. It may be a solute in the form of non-ionic organic acids, or in an ionic form as ammonium ($NH_4^+$), nitrite ($NO_2^-$) or nitrate ($NO_3^-$) ions. Thus, mechanisms to prevent the loss to the environment of potential pollutants, whether they be essential biotic nutrients as solutes or ‘salts’, requires a range of strategies.

Australia has 30% of its soils affected by “sodicity” which is an excess of sodium ‘salts’. Sodic soils are a result of higher than desirable amounts of sodium attached to the charges associated with clay soil. This is typically referred to as the soil Exchangeable Sodium Percentage (ESP). Soils with an ESP grater than 6% are considered sodic. Soil sodicity promotes swelling and dispersion of wetted clay particles causing a collapse in soil structure and/or surface crusting. Such a breakdown in soil structure reduces both the size and amount of pores found in the soil and subsequently reduces a soil's permeability to air and water[20]. It also reduces soil strength and resistance to root movement. Once soils have collapsed infiltration into and percolation within the soil is grammatically reduced. To ameliorate sodic soils, gypsum is applied to allow calcium ions to replace the sodium ions on the clay particles.

Naturally occurring "saline" soils affect approximately 6% of Australian soils with increasing areas occurring due to European farming practices. Saline seeps occur where rising ground water levels bring naturally occurring and applied salts to the surface or where soil erosion strips a site of its topsoil and exposes naturally high saline subsoil. Soil salinity is discussed further Section 5.4 above.

Saline and sodic soils can be treated with calculated and designed applications of manure (OM) and effluent to stabilise and improve soil structure to prevent erosion or plant appropriate deep rooting pasture species or trees so that the water table is lowered and salts are kept at sub surface levels.

Crop yield can be affected by saline soils and the application of saline water. Soil salinity is an excess of soluble 'salts' that cause an adverse osmotic gradient between the plant and the soil. This results in water moving from the plant to the soil and it essentially starves the plant of water and nutrient. The plant once starved of the water and nutrient can then succumb to the affects of a toxic soil environment. Plants growing in an area of saline soil exhibit symptoms of retarded growth, lack of vigour, darkening of leaves, chlorosis or necrosis of the leaves and premature wilting.

Saline soils pose a problem for crop production because they limit the types of crops that can be grown based on their tolerance or sensitivity. Saline soils reduce crop yield and the efficiency in which crops are grown. The impact of salinity on crop performance can be calculated using the formula detailed below[21]:

$$Yr = 100 - B(\mathrm{ECse} - A)$$

where

Yr = relative yield
A = Salinity threshold above which yield is affected
B = % yield reduction per dS/m above the threshold
ECse = average root zone salinity (dS/m)

Highly tolerant crops are barley and triticale. Crops with a moderate level of tolerance of saline soils include, wheat, oats, sorghum, and maize. As a general rule sand loam and clay soils with an electrical conductivity above 0.4dS/m and 0.7dS/m are considered saline. However, the effect of salinity on plant yield are dependant upon the plants tolerance of saline conditions (ie 'A' will vary from species to species).

In summary, soil has a limited ability to adsorb nutrients and therefore cannot be continuously loaded with out leakage of nutrients in various solute and salt forms as it approaches saturation. Imbalances in the loading of solutes and salts can also result in failure of the system by BOD overload under anaerobic conditions, or soil structural collapse due to sodicity.

The critical factors in managing all ‘salts’ within an agricultural system are;

- maintenance of soil water and nutrient storage capacity;
- maximisation of plant growth and transpiration rates;
- removal of nutrients and salts by plant material; and
- management of percolation so that soil water accessions to ground water does not raise levels of water tables, and the loss of solutes and salts in leachate is limited.

**- IMPORTANT -**
**NOTES, HINTS AND TIPS**

- Soils with an ESP > 6% are sodic.
- Gypsum is usually applied to rectify “sodicity”.
- Sand loam and clay soils with an electrical conductivity above 0.4dS/m and 0.7dS/m are considered saline.
- A “leaching fraction” is usually used to flush “salts” below the root zone and to manage “salinity”.

### 5.5 Feeding the Plant

Available water and nutrient deficiencies directly limit the dry matter yield of a crop. Nutrient concentrations fluctuate less than yield itself, therefore, yield is commonly the major determinant of nutrient removal by forage crops in dryland situations[22]. . Typically yield is directly related to the relative abundance of water. While many nutrient deficiencies limit yield, nitrogen is most often the limiting element and it has a direct influence on both yield and crop quality.

Nutrient concentrations may increase, decrease, or remain stable as yield increases, depending on the conditions under which yield increases occur. Increasing the supply of a deficient nutrient will increase crop yield and the nutrient concentration in the plant until the requirement is met. Any additional input of nutrient may not necessarily increase dry matter yield but may continue to increase the nutrient content in the crop[23].

The nutrient concentration in plant tissue that yields 90% or more of the maximum yield is considered to be “adequate” while lower concentrations are considered to be critical or deficient concentrations. As plant nutrient concentrations increase toward the adequate level the plant maintains normal growth but can continue to absorb the nutrient without increasing yield. This condition is termed luxury consumption. Excessive absorption of a nutrient or element can be toxic to the plant and can reduce yield, directly or indirectly[24] (refer to Figure 6).

Different crops require different levels of nutrients to optimise growth and production. Table 4 below illustrates the different levels of nutrient content in soil required to optimise individual crop responses.

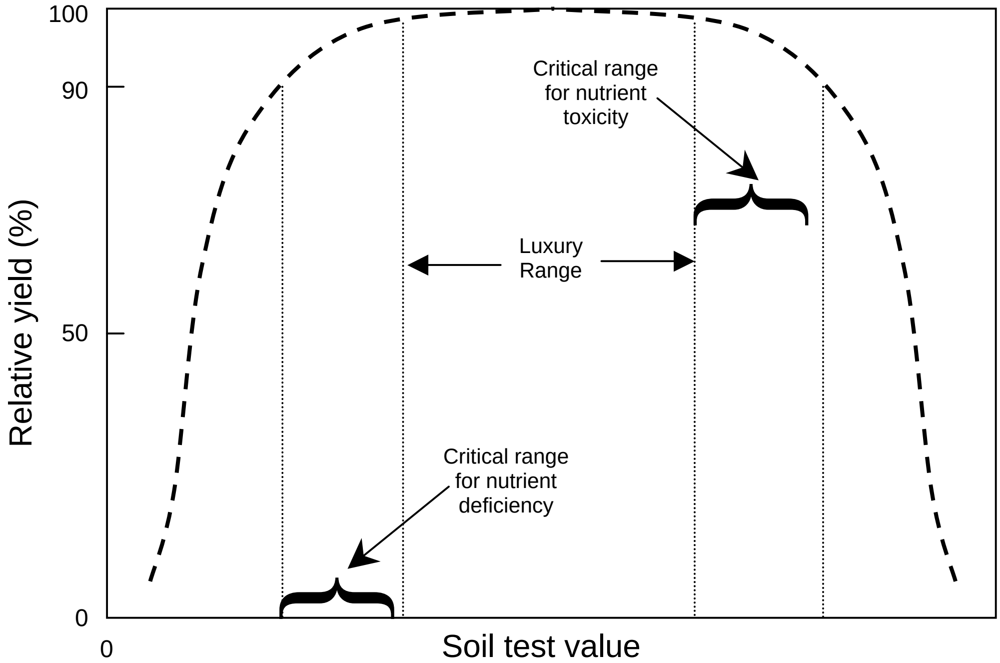



**Figure 6** Generalised relationship between plant yield and nutrient concentration most frequently found in soils.

**Table 4.** Crop Nutrient Concentrations

| Crop | | **Barley** (*Hordeum vulgare*) | | | **Oats** (*Avena sativa*) | | | **Triticale** (*X Triticosecale*) | | | **Wheat** (*Triticum aestivum*) | | | **Canola** (*Brassica napus*) | | | **Cotton** (*Gossypium hirsutum*) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Level | Min | Avg | Max | Min | Avg | Max | Min | Avg | Max | Min | Avg | Max | Min | Avg | Max | Min | Avg | Max |
| Nitrogen | (%) | 1.3 | 3 | 4 | 2 | 2.5 | 3 | | | | <1.5 | 1.8 | 3 | 2.5 | 4.5 | 5.5 | 2.13 | 2.3 | 2.47 |
| Phosphorus | (%) | 0.3 | 0.4 | 0.5 | 0.3 | 0.4 | 0.6 | | | | 0.15 | 0.2 | 0.5 | 0.2 | >0.23 | | 0.19 | 0.3 | |
| Potassium | (%) | 0.8 | 3 | 5.5 | 1.5 | 4 | 5 | | | | 1.25 | 1.5 | 3 | | | | 2.75 | 3 | 3.25 |
| Sulphur | (%) | 0.15 | 0.15 – 0.4 | 0.4 | 0.2 | 0.3 | 0.4 | | | | 0.06 | 0.15 | 0.4 | 0.3 | 0.5 | 0.9 | 0.15 | 0.35 | 0.6 |
| Calcium | (%) | 0.34 | 0.7 | 1.2 | 0.2 | 0.3 | 0.5 | | | | <0.2 | 0.35 | 0.5 | | | | | | |
| Magnesium | (%) | 0.15 | 0.25 | 0.6 | 0.15 | 0.25 | 0.5 | | | | <0.15 | 0.3 | 0.5 | 0.3 | | | | | |
| Sodium | (%) | | | | | | | | | | | | | | | | | | |
| Chlorine | (%) | | | | | | | | | | 0.3 | | | | | | | | |
| Copper | (mg/kg) | 4 | 5.5 | 11 | 3 | 8 | 15 | | | | <5 | 15 | 25 | 2 | 4 | 6 | 7 | 13 | |
| Zinc | (mg/kg) | 25 | 50 | 100 | 15 | 40 | 70 | 31 | 38 | 46 | <15 | 50 | 70 | 29 | | | 16 | 35 | 55 |
| Manganese | (mg/kg) | 8 | 50 | 100 | 17 | 60 | 100 | 11 | | 1000 | 5 | 50 | 100 | | | | 128 | 250 | 570 |
| Iron | (mg/kg) | | 40 - 60 | | 40 | 60 | 140 | | | | <25 | 60 | 100 | | | | <47 | | |
| Aluminium | (mg/kg) | | | | | | 70 | | | | | | 2.2 | | | | | | 170 |
| Boron | (mg/kg) | | 15 | 30 | 5 | 8 | 20 | | | | <6 | 8 | 10 | | | | 80 | 146 | 160 |
| Molybdenum | (mg/kg) | | 0.1 | 0.18 | 0.2 | 0.25 | 0.3 | | | | <0.09 | 0.14 | 0.18 | | | | | 1.2 | |

| Crop | | **Sorghum** (*Sorghum vulgare*) | | | **Maize** (*Zea mays*) | | | **Subterranean Clover** (Trifolium subterraneum) | | | **Perennial Ryegrass** (*Lolium perenne*) | | | **Lucerne** (*Medicago sativa*) | | | **Rhodes grass** (*Chloris gayana*) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Level | Min | Avg | Max | Min | Avg | Max | Min | Avg | Max | Min | Avg | Max | Min | Avg | Max | Min | Avg | Max |
| Nitrogen | (%) | 1.5 | 2 | 4 | 3.5 | | 5 | | 3.0 | | 2.0 | 4.0 | 6.0 | 2.8 | 3.5 | 5.0 | | | |
| Phosphorus | (%) | 0.2 | 0.3 | 0.6 | 0.25 | 0.4 | 0.5 | 0.24 | 0.3 | 0.5 | 0.15 | 0.40 | 0.75 | 0.2 | 0.25 | 0.45 | 0.2 | 0.25 | |
| Potassium | (%) | 2 | 3.5 | 4 | 2.6 | 3 | 4 | 2.5 | 4.0 | | 1.4 | 3.0 | 7.0 | 1.0 | 2.0 | 2.5 | 3.42 | | |
| Sulphur | (%) | 0.1 | 0.11 | 0.2 | 0.15 | 0.3 | 0.5 | 0.2 | 2.5 - 4.0 | | 0.18 | 0.40 | 0.65 | 0.17 | 0.2 - 0.3 | | | 0.1 | |
| Calcium | (%) | 1 | 1.3 | 1.5 | | 0.3 | 0.7 | | 1.0 - 2.0 | | 0.2 | 0.6 | 1.2 | | 1.0 - 2.0 | | | | |
| Magnesium | (%) | 0.2 | 0.4 | 0.8 | 0.3 | 0.45 | 0.8 | 0.1 | 0.2 - 0.7 | | 0.1 | 0.3 | 0.5 | 0.1 | 0.2 - 0.5 | 0.65 | | | |
| Sodium | (%) | | | | | | | | | 0.7 | | | | | | 0.6 | | | |
| Chlorine | (%) | | | | | 0.08 | 1.4 | | | 1.9 | | | | | | | | | |
| Copper | (mg/kg) | 8 | 11 | 15 | | 12 | 20 | | 2 - 3 | | 5 | | 12 | | 5 - 15 | | | | |
| Zinc | (mg/kg) | 20 | 45 | 150 | 11 | 20 - 60 | >60 | | 25 | | 20 | | 50 | | 12 - 18 | | | | |
| Manganese | (mg/kg) | 40 | 70 | 150 | | 20 - 200 | 300 | | 30 - 100 | | 40 | | 100 | | 25 - 35 | | | | |
| Iron | (mg/kg) | 60 | 120 | 300 | | 50 - 250 | 250 | | | | | 50 - 60 | | | 45 - 60 | | | | |
| Aluminium | (mg/kg) | | | 70 | | 100 | | | | | | | | | | | | | |
| Boron | (mg/kg) | 10 | 13 | 25 | | 25 | >25 | | 25 - 60 | | | 6 - 12 | | | 25 -35 | | | | |
| Molybdenum | (mg/kg) | | | | | 0.1 - 10 | >10 | | 0.5 - 1.0 | | 0.15 | | 0.5 | 0.1 | 0.15 | 0.3 | | | |

While Figure 4 illustrates the generalised relationship between crop yield and tissue nutrient concentration, it is equally important to note that there are interdependences between the uptake of some nutrients as well as antagonistic relationships between relative uptake of others. The interaction between the uptake of nutrients is complex. A balanced nutrient supply is best described through fixed ratios between the supply of nutrients to the plant. Plant N:P uptake ratios range from 4.5:1 to 9:1. Therefore the supply of N and P should be aimed at a similar balance. Unfortunately the supply in feedlot manure is about 2:1 to 3:1. The ratio in effluent is highly variable. Given that the nutrient levels in the manure or effluent may be out of balance it is important to determine the nutrient status of the soil. The application rate can then be accurately determined as can other nutrient deficiencies or toxicities that may need to be offset with specific inorganic fertiliser or ameliorant applications.

Table 5 describes a general soil fertility guide. The level of nutrient needed to meet “adequate” plant nutrition is considered to be “moderate” in the table.

**Table 5.** Soil Test Levels Commonly Used by Laboratories. (Values based on a collation of those used by 4 commercial laboratories).

| Parameter | Determination | Units | Very Low (VL) | Low (L) | Moderate (M) | High (H) | Very High (VH) |
|---|---|---|---|---|---|---|---|
| Conductivity | 1:5 water | ms $cm^{-1}$ | | < 0.3 | 0.3 - 0.7 | > 0.7 | |
| EC se | Calculation | dS $cm^{-1}$ | | < 2.0 | 2.0 - 5.0 | > 5.0 | |
| Total Soluble Salts | 1:5 soil water | mg $kg^{-1}$ | < 500 | 500 - 700 | 700 - 1150 | > 1150 | |
| Organic Matter | Walkley - Black | % | < 1.5 | 1.5 - 2.5 | 2.5 - 3.5 | > 3.5 | |
| $NO_3$-N | 1:5 water extract | mg $kg^{-1}$ | < 10 | 10 to 20 | 20 - 60 | > 60 | |
| P | Bray 1 | mg $kg^{-1}$ | <12.5 | 12.5 - 25 | 25 - 35 | > 35 | |
| P | Colwell (bicarb extr.) | mg $kg^{-1}$ | <15 | 15-30 | 30-50 | >50 | >150 |
| $SO_4^{2-}$ | calc.-phosph. extract | mg $kg^{-1}$ | < 3.5 | 3.5 - 6.6 | 6.5 - 11.5 | > 11.5 | |
| Ca | $NH_4$ acetate extract | meq/100g | < 0.5 | 0.5 - 1.0 | 1 - 2.5 | > 2.5 | >10 |
| Mg | $NH_4$ acetate extract | meq/100g | < 0.2 | 0.2 - 0.4 | 0.4 - 0.8 | 0.8 - 2.0 | >2.0 |
| K | $NH_4$ acetate extract | meq/100g | < 0.1 | 0.1 - 0.3 | 0.3 - 0.5 | > 0.5 | |
| Na | $NH_4$ acetate extract | meq/100g | < 0.05 | 0.05 - 0.2 | 0.2 - 0.5 | 0.5 - 1.0 | > 1.0 |
| Ca | $NH_4$ acetate extract | mg $kg^{-1}$ | <525 | 525 - 1150 | 1150 - 2000 | > 2000 | |
| Mg | $NH_4$ acetate extract | mg $kg^{-1}$ | < 100 | 100 - 185 | 185 - 425 | > 600 | |
| K | $NH_4$ acetate extract | mg $kg^{-1}$ | < 60 | 60 - 185 | 185 - 225 | > 225 | |
| Na | $NH_4$ acetate extract | mg $kg^{-1}$ | < 75 | 75 - 125 | 125 - 275 | > 275 | |
| Al | 1:5 0.01M $CaCl_2$ | mg $kg^{-1}$ | < 3.8 | 3.8 - 6.3 | 6.3 - 8.8 | > 8.8 | |
| Cl | 1:5 water extract | mg $kg^{-1}$ | < 75 | 75 - 150 | 150 - 300 | 300 - 600 | > 600 |
| Cu | DTPA extract | mg $kg^{-1}$ | < 0.1 | 0.1 - 0.3 | 0.3 - 2.0 | 2.0 - 10.0 | > 10 |
| Cu | EDTA/ammon. bicarb. | mg $kg^{-1}$ | < 2 | 2 - 4.5 | 4.5 - 8 | > 8 | |
| Fe | DTPA extract | mg $kg^{-1}$ | < 1 | 1.0 - 10 | 10 - 100 | > 100 | |
| Fe | EDTA/ammon. bicarb. | mg $kg^{-1}$ | < 60 | 60 - 140 | 140 - 350 | > 350 | |
| Zn | DTPA extract | mg $kg^{-1}$ | < 0.1 | 0.1 - 0.3 | 0.3 - 1.0 | 1.0 - 10.0 | > 10 |
| Zn | EDTA/ammon. bicarb. | mg $kg^{-1}$ | < 2 | 2 to 5 | 5 - 8.5 | > 8.5 | |
| Mn | EDTA/ammon. bicarb. | mg $kg^{-1}$ | < 45 | 45 - 130 | 130 - 350 | > 350 | |
| B | hot 0.01M Ca $Cl_2$ | mg $kg^{-1}$ | < 0.1 | 0.1 - 0.5 | 0.5 - 2.0 | > 2.0 | |
| B | hot water / $MgCl_2$ | mg $kg^{-1}$ | < 0.8 | 0.8 - 1.5 | 1.5 - 3.5 | > 3.5 | |
| Mo | anion exchange | mg $kg^{-1}$ | < 0.07 | 0.07 - 0.25 | 0.25 - 0.7 | > 0.7 | |

*Important Note -* These values should be used only as a guide. They are most applicable to soils with low to moderate clay contents and acidic to neutral conditions. Agronomic advice should be sought for individual test results. Further information can be obtained from Glendinning and Pevirill *et. al.*[25]

### *5.5.1 Luxury Uptake of Nutrients by Plants*

The nutrient content of the crop is dependent upon a number of factors. A primary influence on concentrations of an element is the relative abundance of it in the soil. Under a given set of growth conditions it has been shown that the uptake of solutes by roots (hence plant tissue concentration) is related to their concentration in the soil solution and the extent buffered by the soil[26].

Often crops grown in areas receiving manure and effluent have nutrient and salt concentrations above typical values and removal rates can be an order of magnitude higher than those encountered in typical crop production. Depressed yields have been noted at high application rates of manure, with the N content of the harvested forage ranging from 0.69 to 1.42% for the highest (320t dry basis/acre) application rate, indicating N uptake approached a maximum[27]. FLOT202 demonstrated a similar relationship with measurement of a strong relationship between the concentration of P in plant dry matter and soil Colwell-P[28] (see 0). The effects of buffering capacity on soils were illustrated when the experimentation found that the highest uptake of soil P occurred on the soil with the lowest buffering capacity[29].

The proven ability of plants to concentrate elements in tissue beyond their nutritional requirements is useful when exporting from the profile a potentially large nutrient pool from manure and effluent application. In essence, equilibrium in the soil-plant system may be achieved where relatively high application rates of nutrient and salt are matched by a corresponding high crop removal rate. In summary, the rate of removal of crop nutrients and salts is therefore a function of both dry matter production and nutrient/salt concentration in plant tissue. By marrying the gross amount of dry matter harvested with its chemical composition, a measurement of nutrient and salt removal by the plant is obtained. Silage crops (corn or sorghum) recycle nutrients well because they produce more plant material (Dry Matter - DM), and harvesting the silage removes more nutrients from the land application area than do other crops[30].

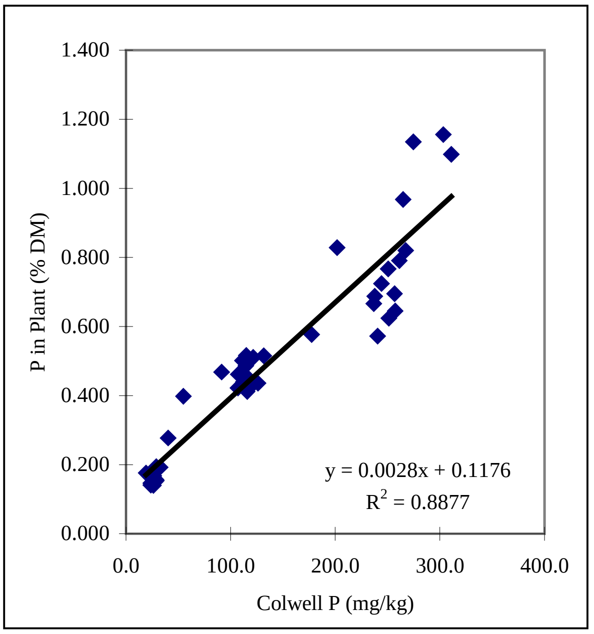



**Figure 7** - P in Plant (%) Versus Soil Colwell P - Sandy Loam Soil

## - IMPORTANT -
## NOTES, HINTS AND TIPS

- Nutrient removal is a fraction of yield and crop nutrient content.
- Nutrient content required by plants varies between crops.
- Nutrient supply can be customised as a result of soil nutrient content and plant requirement.
- Crop performance is related to nutrient supply and ratios between nutrients. The ideal nutrient ratio for a plant is:

| N | : | P | : | K | : | S |
|---|---|---|---|---|---|---|
| 5 | : | 1 | : | 6 | : | 1.5 |

### 6. Effect of Manure on Soil

The land application of manure may provide the soil with nutrients and organic matter. This can improve the soil nutrient cycle; the physical state of the soil and therefore plant growth, at the same time reducing a potential ‘waste disposal problem’. In the later case this is more a case of perception because manures are more often a resource in the wrong place than a ‘problem’.

When manures are added to soil they can reduce the soil bulk density. Fibrous manures, such as feedlot manure, reduce bulk density more than poultry manure[31]. The two major factors contributing to the change in bulk density are the organic matter additions and improved soil aggregation.

It has been found that aggregate stability and infiltration rates increased with increasing rates of manure application until excess application rates of sodium and potassium caused a reversal in soil structural stability. The higher infiltration at low to medium manure application rates was directly attributable to improved soil organic matter. Several researchers have reported lower runoff volumes and soil erosion on plots receiving animal manure than on control plots receiving no manure. Research in the project FLOT 202 found that the organic matter content of a soil and soil aggregation relate inversely to rainfall-runoff and soil loss[32]. The data in Figure 10 show that the gross amount of water lost was significantly less than from the manured treatments than the control. This is due to improved infiltration rates which results in more rainfall being stored in the soil and therefore, less runoff.

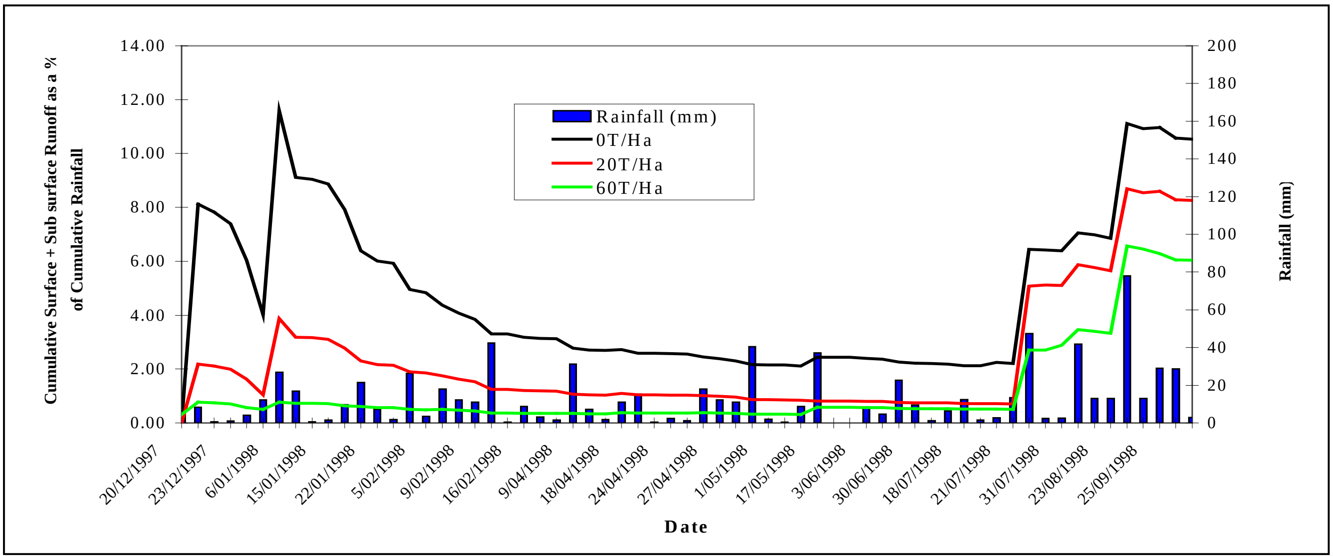



**Figure 10** Cumulative Surface + Subsurface Loss of Water as a % of Cumulative Rainfall – Tullimba Experimental Feedlot Small Plots

The cation exchange capacity of a soil gives an indication of the gross amount of charge in a soil and it directly effects the soils nutrient and water holding capacity. Therefore, the presence of organic matter influences a soil's ability to capture and hold water and nutrient. The application of manure to soils improves organic matter levels, and in particular the cation exchange capacity of a soil. The value of manure can be increased accordingly. Improvements in water use efficiencies (soil capture, retention, and supply to the plant) of greater than 10% are achievable on loam soils. This improvement in water efficiency may increase the value of manure by as much as $20/T/year (depending upon the value of the irrigation water).

FLOT 202 research also found that manure amended soils produced higher yielding crops (see Table 6). While increased nutrient availability was a significant factor in the higher crop yields achieved in amended soils, the higher productivity also was due to increased levels of organic carbon provided by manure. It helped to create a more stable soil structure, which in turn increased water infiltration and reduced runoff. An extension of this finding is that manure will assist in reducing soil erosion as manure treated soils increase the capacity to hold moisture and nutrients which is directly related to a significant increase in the cation exchange capacity (see Figure 10).

The uptake of nutrient is limited to the rooting depth of the crop and the movement of nutrient deep into the soil profile is often limited by soil physical and chemical constraints. For instance, some soils have quite impermeable subsoils, or an uneven nutrient removal rate over the profile. This affects the movement of nutrients beyond the plough layer[33]. Leakage of solutes from a soil receiving waste waters is not limited to flushing of 'salts'. As previously discussed in Section 5.4, all manner of solutes move through soils in leachate. Figure 11 shows that the gross amount of phosphorus (P) lost in leachate from a acid sandy loam can be related to the available soil P[34,28]. It shows that soils tend to leak P in increased concentrations and well before they have reached saturation levels consistent with that defined using a p isotherm. Equally, in heavy clay soils with a neutral or alkaline pH, precipitation of insoluble calcium phosphate removed P from the system. A considerable amount of Ca is also added in effluent and therefore Ca interactions with P must consider this continual input as well as the resident Ca effects on the ability of the soil to retain P.

The soils in the FLOT 202 plots and pot trials receive different amounts of beef cattle feedlot manure and effluent. The increase in soil available P was directly related to increasing rate of application. The measurement of P in the leachate was total phosphorus. Specification of the P found that a considerable amount of the P was in the organic form. These complex molecules, or solutes, while dissolved in water are weakly charged and can move in leachate especially where the soil attractive forces (which can be estimated by its CEC) are limited. Figure 11 also shows that the heavy clay soil, which had received the same rates of wastes, did not release P in the same quantities for a given soil available P concentration. The data show that this heavy soil was able to limit loss of both P salts and solutes.

**Table 6.** Dry Matter yield (kg/ha) of Forage Sorghum and Triticale for Year 1 and 2.

| Treatments (manure T DM/ha) | | | Year 1 Sorghum | | | Total Year 1 | Year 2 Sorghum | | Total to date Year 2 |
|---|---|---|---|---|---|---|---|---|---|
| Year 1 | Year 2 | Effluent | Harvest 1 | Harvest 2 | Triticale | | Harvest 1 | Harvest 2 | |
| 0 | 0 | - | 2039 | 1563 | 2280 | 5882 | 831 | 1482 | 2313 |
| 0 | 0 | + | | | | | 711 | 1302 | 2013 |
| 20 | 25 | - | 4158 | 2765 | 3793 | 10716 | 5853 | 6444 | 12297 |
| 20 | 25 | + | | | | | 6004 | 7583 | 13587 |
| 20 | 25(N)* | - | | | | | 7559 | 10344 | **17903** |
| 60 | 0(N) | - | 5807 | 6431 | 6620 | 18858 | 5015 | 8489 | 13504 |
| 60 | 0(N) | + | | | | | 5800 | 9818 | **15618** |
| Inorg[#] | Inorg[#] | - | 4664 | 7618 | 9908 | 22190 | 3468 | 7764 | 11232 |

* N applied as urea

[#] The inorganic fertiliser (NPKS) was applied 4 times through each crop growth period and applied at a rate to achieve a projected 'maximum' growth.

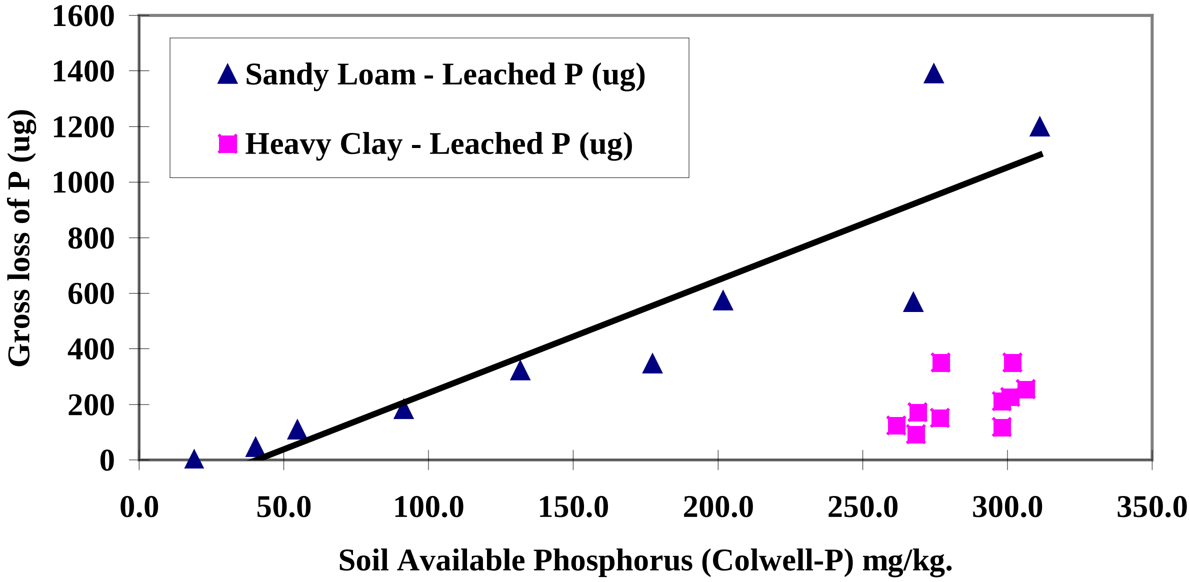



**Figure 11** Gross Loss of P in Leachate from a Sandy Loam and Heavy Clay - Pot Experiment

In summary, manures are a major source of organic matter, while manures also increase; CEC, infiltration, and plant available water. The benefits of manure application increase with increasing manure application rates and they are profound in light soils (loams) and least noticeable on heavy well structured clays (eg. montmorillinite clays). Manure additions to poorly buffered soils (with low CECs) have the greatest positive impact on soil structure and water relationships and therefore crop performance.

**- IMPORTANT -**
**NOTES, HINTS AND TIPS**

- Well structured clays benefit least from manure applications with respect to nutrient and water supply
- Any soil with structural problems whether it be a clay or a sandy loam will have improved water capture and retention with manure applications
- Increasing organic matter content in soil through the application of feedlot manures increases infiltration and water holding capacity and thus increases the proportion of rainfall that is captured by the soil-plant system.
- The improved soil water relations and soil health gives improved plant production that in turn promotes a greater and more effective water usage and nutrient uptake.

# 7 EFFECTS OF WASTE WATER APPLICATION

Irrigation is a common method of utilising liquid effluent from cattle feedlots. The effluent is derived from rainfall-runoff from within the controlled drainage area. Its quality varies from feedlot to feedlot and year to year. Disposal of effluent can occur through evaporation, treatment or irrigation. Irrigation of effluent aims to have the water, nutrients and salts utilised by pasture or crop growth. Its reuse must be properly managed to minimise possible adverse environmental consequences and to maximise agricultural production and returns on the capital investment in irrigation infrastructure.

The management of effluent irrigation is more complex than normal irrigation using good quality water. Feedlot runoff usually contains nutrients and salts, either dissolved or suspended in the water. While the nutrients can be a valuable source of fertiliser for an irrigated crop if the effluent is applied at an appropriate rate, the salts may be harmful to young crops or cause degradation of the soil structure by accumulating in the soil. Feedlot effluent application rates are usually limited by either nitrogen, salinity or sodium content[35].

Because holding pond water contains plant nutrients such as nitrogen, phosphorous and potassium, its application on agricultural land, in correct amounts, can increase crop yield[36]. Traditionally, waste application rates that supplied nutrients in amounts equal to crop utilisation, have been recommended, because higher applications could potentially reduce drainage water quality and soil productivity[37]. This approach to land utilisation of waste means that the system is sustainable.

Feedlot runoff stored in holding ponds generally has an electrical conductivity (EC) of 1 to 10 dS/cm, depending on factors such as cattle ration, stocking density and degree of evaporation. Salt in irrigation water can potentially cause problems if application rates are not supplemented with clean water (or water with relatively low salinity), or the irrigation water has high concentrations of Na. Sodium adsorption ratios in excess of 15 are usually considered unacceptable[38]. Sodium concentrations should therefore be closely monitored.

## 7.1 Leaching fraction

Salts can accumulate in the soil when too much feedlot effluent is applied. This is especially the case in areas where precipitation is too low to leach salts downwards below the root zone. Under proper irrigation, some soils can take as much as one or two tons of salt per acre each year without detrimental results. The amount depends on several factors including soil texture, irrigation depth and rainfall. The amount of 'salt' that can be loaded onto an effluent irrigation area can be calculated and used to determine the annual average amount of waste water that can be applied and also the amount of salt that must be moved below the root zone to prevent salt accumulation. Dilution of holding pond water with good quality fresh water can be used to minimise the potential for reducing the land's productivity. In most cases clean water is needed for irrigation to achieve the desirable levels of deliberately leaching of the soil profile by drainage. This required drainage is called the 'Leaching Fraction' (LF) and is a directly related to the salinity of the waste water applied and the salinity level at which crops can tolerate. That is, the more saline the irrigation water the higher the LF. The practical range of LF for a variety of irrigation water qualities is illustrates in Table 7[39].

Several researchers have found that concentrations of pollutants and salt concentrations in holding pond water increase over time due to evaporative loss[40]. Power recommend, for Kansas, that one part of feedlot effluent should be diluted with four parts of clean water.

This is qualified with the comment that dilution ratio can vary with clean water quality, soil and crop type, and effluent quality.

**Table 7.** Leaching Fractions required as a result of salinity in irrigation waste water, assuming a maximum soil salinity (ECe) of 4 dS/m.

| Irrigation Water Salinity EC (µS/cm) | Leaching Fraction LF (%) |
|---|---|
| 200 | 2.5 |
| 400 | 5 |
| 600 | 7.5 |
| 800 | 10 |
| 1000 | 12.5 |

## 7.2 Clean Water Irrigation Supply

The main objective of irrigation is to provide plants with sufficient water to prevent moisture stress that may result in reduced yield. Irrigation of feedlot effluent is significantly affected by irrigation practices, the crop grown, and the soil type and depth. Continued safe onsite disposal of waste waters is ultimately dependent upon maintaining the health of the soil-plant system receiving the waste water. The critical determinant is not a single parameter but rather the balance between hydraulic loading, waste loading versus the net removal or loss of nutrient from the system and continuance of stable soil chemistry. Where excess nutrient occurs, environmental hazard increases.

Therefore, the proper management of feedlot effluent irrigation is essential if the feedlot operation is going to be environmentally sustainable and to maximise economic returns from waste reuse and irrigation infrastructure. The management of the irrigation area is dependent on the application system, application rate, crop type, soil type and depth and the availability of clean irrigation water. In high moisture deficit areas clean water will be required for the dilution of effluent prior to its application to land or to fulfil the plants requirements. This enhances the leaching of excess salt below the root zone and reduces the likelihood of soil degradation. If clean water is available in addition to effluent then crop productivity and nutrient uptake can be increased. This may allow the size of effluent irrigation areas to be reduced below that defined by the sustainable application of just the nutrient and salts in effluent

Typical surface methods used for feedlot effluent irrigation include furrow, contour ditch and border check. Spray irrigation methods are generally preferred for effluent irrigation due to the reduced potential for runoff and tailwater generation, greater uniformity of application and the ability to more accurately apply smaller quantities more regularly. Typical spray methods include hand shift spray lines, travellers, centre pivots and lateral moves.

Sweeten[41] states that sprinkler irrigation is the preferred approach to land application of feedlot runoff because sprinklers allow for controlled, low application rates (eg. 10 mm), if necessary, to prevent runoff. Flood irrigation (eg. furrow) usually creates a tailwater problem in fine textured soils because it is difficult to apply less than 75 mm per irrigation to get complete coverage. High application rates may result in excessive soil loading rates for nutrients and salts.

In most states of Australia regulations require that waste water irrigation areas are formally defined have dedicated tailwater capture and recycling systems.  The capture of tailwater has the potential to provide a 'grey water' that can be used to further dilute effluent.

In summary, clean irrigation water should be used to supplement effluent irrigation so that rather than applying water at a "supplementary" rate, operators can strive to achieve "full" irrigation.  This may actually allow the liquid utilisation area to be reduced in size because of the potentially greater uptake of nutrient by crop.  It is recommend that feedlot managers should regularly test the quality of their effluent irrigation water, clean irrigation water and soil.

**- IMPORTANT -**
**NOTES, HINTS AND TIPS**

- Design 'Irrigation Systems' and 'Land Area' to include a leaching fraction.
- Well structured clay soil are more resilient against soil structure decline caused by salinity and sodicity through effluent applications, however once an imbalance has occurred they will take the longest and incur the greatest cost to remediate.
- Clean irrigation water should be used to supplement effluent irrigation.

## 8 MANAGEMENT PRACTICES

There are several recommended practices for profitable and sustainable utilisation of wastes.  The following principals are as applicable to feedlot farms as they are the mainstream users of manure and effluent products.

- A nutrient management plan (NMP) should be developed for each effluent irrigation and/or manure application area.  The NMP should allow for manure applications every two or three years.  Manure applications and cropping regimes should be focused on the sustainable utilisation of nutrient from manure and or effluent.
- The nutrient management plan may require the use of inorganic fertilisers and clean water irrigation so that crop uptake of nutrient is balanced and not impaired by seasonal conditions.
- Applying manure every two to three years rather than annually can save costs incurred by incorporation and spreading operations.  This combines well with tillage practices and soil fertility management.
- Application rates should be based on soil tests taken prior to preparation of a soil for planting.  The nutrient management plan should also include in its calculations the amount of plant available nutrient resident in the soil.  The fertiliser recommendations for a particular crop and yield goal should not be exceeded.
- Effluent irrigation or manure application should not be spread near bores nor near watercourses as per State guidelines.
- Effluent irrigation should only be undertaken when a crop is actively growing and is best undertaken when the soil is in a healthy state.
- Manure should be spread after harvest and prior to initial land preparation, ie. the soil profile has dried.  This will reduce soil compaction because the land can better support

the equipment. Multi-axle spreaders with flotation tyres reduce near surface and deep compaction. Axle loads should be kept under 7 T/axle. Spreading should be undertaken as close to crop plant as possible in light soils.
- Manure should be applied as close to crop plant as possible. This is especially the case with light soils where the potential for leaching is greatest.
- Incorporate the manure on the day of application. This breaks-up and mixes the manure into the soil and reduces nitrogen loss and placement of phosphorous in the root zone. Increasing the degree of incorporation reduces nitrogen loss from manure. Tined equipment incorporates manure less than disc machinery.
- Soil ameliorants such as gypsum and lime should be added to address any imbalances in the soil exchange complex.

Mass balance calculations in a NMP show that the limiting elements applied in manure and effluent are most often ‘salts’ such as sodium. It has been an accepted practice to add ‘salts’ at a far higher rate than the plants requirement, because rainfall and clean irrigation water can remove it from the soil system by leaching. This philosophy requires that sufficient deep drainage occurs to remove the excess salt. In some areas deep drainage below the root zone is small and accumulation of salt can occur. If the possibility of salt build up does not restrict application rates, then the limiting factors for application rates are most likely to be P and K. This means that some key elements (especially N) will be deficient. It is important that inorganic fertilisers be applied to the land to fill any deficiencies and thus allow the target yield to be met. In most cases an application of inorganic N is required in conjunction with manure and/or effluent usage to achieve a balanced nutrient profile.

## 8.1 Crop Removal and Crop Program

The first step in determining the nutrient management program is to define the areas that will be cropped and the cropping programme. The cropping programme should be kept simple and achievable. A good cropping programme is typically planned over a three to five year period. Once these parameters have been defined the next step is to estimate the yield of pasture hay, silage, grain and stubble hay that is likely to be generated.

A typical cropping programme for a feedlot farm is shown in Table 8 below.

**Table 8.** Basic Crop Rotations for a Farm.

| *Date* | *Crop* | *Water, Waste Water and Manure Usage* |
|---|---|---|
| April 2000 | Plant Forage Oats | Waste water + Clean Spread manure in March and incorporate |
| August 2000 | Harvest Oats for Silage | Nil |
| October 2000 | Plant Silage Maize | Waste water + Clean |
| March 2001 | Harvest Maize for Silage | Nil |
| April 2001 | Fallow | Nil |
| October 2001 | Plant Silage Maize | Waste water + Clean<br>Spread manure in Aug/Sept and incorporate |
| March 2002 | Harvest Maize for Silage | Nil |
| April 2002 | Plant Barley | Clean Water Only - Break crop |
| December 2002 | Harvest Grain/Bail Stubble | Nil |
| January 2003 | Fallow | Nil |
| October 2003 | Plant Silage Maize | Waste water + Clean |
| March 2004 | Harvest Maize for Silage | Nil |
| April 2004 | Return to Start of Cycle | |

## 8.2 Soil Testing

A soil test should be used by a trained agronomist, soil scientist or agricultural engineer to calculate the quantity of nutrient that is need to sustain crop growth. This is simply gained by defining the following;

- The amount of nutrient readily available in the soil. This is usually the amount of a nutrient in excess of the "adequacy" level or the amount that is deficient in the soil which is the difference between the adequacy level and the actual reading,
- The gross amount that the crop needs to meet its full growth habit and desired quality
- An estimate of the amount of nutrient that may be lost from the soil system through volatilisation, leaching and soil fixation
- An estimate of the amount that may be released through mineralisation of SOM over the life of the crop and the cropping programme in general.

If there is a soil deficiency typically needs to be filled over and above the quantity that the crop needs. The manure application rate (or should be determined for each nutrient using the formula described below.

Required nutrient input = GCR - ASS (or + SND) - Est_M + Est_L

Where;
GCR = Gross Crop Requirement
ASS = Available Soil Store
SND = Soil Nutrient Deficit
Est_M = Estimated supply from mineralisation
Est_L = Estimated loss of nutrient from the system.

Application Rate (T/ha) = Required Nutrient Input (kg/ha) ÷
Manure Nutrient Concentration (kg/T) ÷
Bio-availability of Nutrient

The calculation should be used to determine the limiting nutrient (that is the one with the lowest application rate). The deficiencies for the other nutrients can then be determined and quantities of inorganic fertilisers defined.

### 8.3 Manure Application Rates, Testing and Spreading

Research has shown that the improvements in soil physical characteristics coupled with a balanced soil fertility, obtained from the manure plus some inorganic fertiliser (eg urea), will provide improved crop yields. To obtain the optimum and environmentally sustainable production levels and healthy soils, soil and manure analysis should be conducted to:

- obtain the best balance of nutrition for the crop;
- ensure that toxicities and deficiencies do not occur; and
- monitor long term trends of nutrient concentrations to prevent accumulations to levels that are environmentally hazardous.

In addition to manure application, standard agricultural inorganic fertilisers can be applied to increase any particular nutrient. Farmers can tailor the nutrients available to plants by the types of inorganic fertilisers they choose and the individual crop requirements. For the best results from manure application an application of nitrogen in the form of Urea is the most effective and efficient ways of meeting the plant requirements for nutrients.

*Manure Sampling and Testing*

In the Field

1. A sample of approximately 0.5 to 1.0 kilogram fresh weight of spread manure should be collected.
2. The sample should be placed immediately into a sealed bag or container to prevent moisture loss.
3. Record unique identification information on the bag/container with a black permanent marking pen. This may include: type of contents (manure), collectors name, collection location, original source of manure, date, application rate.
4. Place the samples immediately into a portable refrigerator/freezer or esky to preserve the original chemical condition of the sample during transport.

When and what to sample

1. Manure used as an inorganic fertiliser for cropping can be sampled at the time of application. Place trays in line with the spreading vehicle so that they pass underneath the vehicle and capture the manure as it falls to the ground. The trays should be large enough to capture at least 1 kg of fresh weight. At least 3 replicates from different locations should be taken for a particular application rate.
2. Samples may also need to be taken for planning purposes prior to application or sale of the manure. Samples taken from the manure stockpile should be taken at various depths into the stockpile to account for variation in moisture content.

From the Field to the Laboratory

1. Store sample in a portable refrigerator (<4°C) or cooled container in dark place.
2. Send to laboratory as soon as possible.

**- IMPORTANT -**
**NOTES, HINTS AND TIPS**

- Manure nutrients are normally in a ratio

| | | | | | | |
|---|---|---|---|---|---|---|
| N | : | P | : | K | : | S |
| 2.5 | : | 1 | : | 2 | : | 0.5 |

- Therefore if phosphorous applications match crop demand additional inorganic nitrogen and potassium are needed to meet the ideal nutrient ratio for plants of:

| | | | | | | |
|---|---|---|---|---|---|---|
| N | : | P | : | K | : | S |
| 5 | : | 1 | : | 6 | : | 1.5 |

- All applications of inorganic fertilisers should be based on recommendations following complete soils test of the application area and only once all deductions are made from the gross nutrient requirement from inputs from manure and effluent.

### 8.4 Determining Rates of Waste Water Irrigation

The determination of waste water application rates follows a the same methods as those defined in Section 9.3 above. However it is simpler because it can be generally assumed that the entire nutrient is immediately available and therefore there is no need to include an allowance for long term mineralisation of material it contains. It is important to note that the limiting element (using the above) calculation is most likely to be sodium unless the loss term is expanded to include the ‘loss’ associated with the leaching fraction.

# 9 PROFITING FROM MANURE AND EFFLUENT USE

Proper waste management at any livestock facility is becoming a requirement of its operational license and it ultimately attracts costs. For a beef cattle feedlot it is debatable whether the recovery cost of manure and effluent as resources should be:

- levied directly against the sale of the products on the basis that 'waste management' is a separate cost centre; or
- simply included as a cost to the beef production system with manure and effluent as a potentially useful derivative and by-product that (initially) has a $0 cost and $0 value.

For a farmer purchasing and spreading manure or irrigating effluent the quality and consistency of supply of these products is paramount and the practicality of application of the byproducts of utmost importance.

## 9.1 The Economics of Manure Reuse

Irrespective of the above, it is useful to know the costs of manure production so that these costs can be managed. The economics of manure management are driven by economies of scale and also the management system used. Most feedlots are able to generate a supply of processed manure for a cost of $5-9/T (wet). Raw manure is currently being sold ex feedlot for values in the range of $3-12/T (wet) and partially composted manure can sell for values in the order of $9-20/T.

The cost of feedlot manure management is summarised in the Table 9 below. These costs only take into account the labour and machinery costs associated with manure handling, and exclude any infrastructure costs.

A hidden cost in the management of the manure is loss of mass incurred through the decomposition process. This may be as large as 15% from the time the manure is hauled out of the pens and then finally hauled off the property. The magnitude is directly related to the age of the manure removed from the pens and also the length of time it is kept in the stockpile. A significant stockpile loss may turn the product from being a profit earner, to being a loss generator. The loss should be measured and included in the accounting for manure management costs.

A gross value of $55/T ($40/T fertiliser value + $15/T soil conditioner) can be placed on manure. This value only considers one year of water savings and is therefore an underestimate of the full value of the product. However it is clear that there is a substantial and positive cost differential between recovery cost and the potential sale value. Unfortunately, this sale value is the value of the product to the end user and significant discounting of the product is required if the product is to be purchased and used for their maximum benefit.

Screening is required if the manure contains foreign matter (timber, concrete, rocks etc). The cost of this is significant and any means of eliminating the need for screening (best achieved through good design and pen base material selection) is important to the economics of the operation. Partial composting of the manure through turning the product may cost $3-7/T. While this may seem to be a large cost it does directly add value to the manure product and will make it more saleable.

**Table 9.** Costs of Manure Management.

| Manure management practice | Cost $/T (wet) * |
|---|---|
| Harvest | 0.50-2.50 |
| Load and Haulage to stockpile[a] | 0.50-1.75 |
| Screening | 2.50-4.50 |
| Reload | 0.50-1.25 |
| Sub total | 2.00-10.00 |
| Storage losses | 0.40-1.50 |
| Partial composting | 3.00-7.00 |
| Sub total | 5.50-18.50 |
| Spreading | 4.00-10.00 |

* some data drawn from Powell (1994)[42] {moisture content is 30%}

[a] manure sold off feedlot from pen directly to end user attracts only a loading cost.

Sale returns to the feedlot are increased if haulage and spreading costs are reduced. The spreading costs vary considerably and they range in nature from a cubic meter rate to a per hectare rate. Spreading costs can be reduced through the supply of large quantities and application of manure at higher rates. Equally, haulage costs can be minimised through the use of large trucks. A semi trailer can carry 25 T (wet basis) (or about 17.5 T dry basis) at a per kilometre rate of $3.00 per kilometre. Therefore the cost of cartage is $0.17 per tonne per kilometre. The use of a B-Double will reduce haulage costs substantially. Contract cartage using a B-Double tipper can be reduced to about $4 per kilometre with a load of about 38 tonnes. Some feedlots provide a packaged service of manure sale, haulage, and spreading in an effort to better market the product and increase returns to their operation. Discounting of all of these costs is contingent upon the ease of handling the product.

Overly wet product provides a cost benefit to the feedlot because less manure is sold per tonne weight, but it creates unwanted difficulties in handling, and in particular spreading, and also a lower value product for the end user.

The farmer using manure often has to change soil management practices to incorporate the use of added heavy traffic across their land. With out consideration of this further cost will be incurred. Typically, an additional deep ploughing or ripping is needed to relieve compaction following the spreading operation. The cost of deep ripping varies significantly and across the range of $20 to 60 per hectare. This variance is dependent on soil type, soil moisture, ripping depth and tractor size used. If 10 tonnes (wet) of manure is applied per hectare this equates to an additional cost of $2-6 per tonne for use of the manure as an organic fertiliser as opposed to the convenience of inorganic fertiliser use. The use of multi-axle spreaders with flotation tyres reduces both near surface and deep compaction of the soil (see picture above) and therefore has a significant influence on the gross costs of manure application programs.

It is for the above reasons that tri-annual application of manure is promoted from an economic perspective. Aside from the immediate and profound benefits of soil improvement and greater ease of nutrient management there are a number of cost benefits. These include the ability to:

- obtain discounts in manure spreading and haulage costs and most importantly;
- spread these costs and the costs of additional paddock management over a three year period;

- reduce disruption to farming operations;
- greater flexibility in incorporating organic fertiliser application in a crop rotation, and,
- increased overall nutrient recovery rates and water use efficiency.

In summary the cost of spreading and cartage are pivotal in determining the economies of any manure spreading operation. The cost differential between the sale cost of manure ($10 (wet basis)) and its worth (fertiliser + ameliorant value) is about $35 T (wet basis). On a spreading cost of $10 the radius of economic usage is in the order of 147 kilometres. Economic haul distances increase if tri-annual manure applications are used together with B-Double haulage. The maximum economic haul distance can be extended to about 400 km based on an ex-feedlot sale price of $10/T (wet 30% MC) and 1 year of water savings. This haulage distance can be increased further where soils are degraded (very low carbon contents and saline or sodic conditions) and the soil conditioner value of manure increases substantially because it can be considered in terms of the return of land to productive use.

It is difficult to add these to the 'ameliorant' value of manure for degrade lands at this stage. Those that do state, anecdotally, that they see a greater return. Typically the most positive visual responses occur during dry years when the increased water storage and holding capacity assist crops struggling to find moisture.

**- IMPORTANT -**
**NOTES, HINTS AND TIPS**

- You get more manure for your dollar (per tonne) the dryer manure gets, however dryer, older manure may have less nutrient reducing its fertiliser value.
- Very dry or very wet manure is difficult and costly to spread
- A balance between manure nutrient and moisture content is essential in maximising your investment.

### 9.2 Economics of Effluent Use.

The economics of effluent irrigation are more difficult to quantify than those associated with manure harvest and sale. In most cases effluent is applied to the feedlot farm and is not sold off-site. The land application of waste waters is typically a licence condition and the infrastructure development part of the feedlot complex. Therefore the economics of waste water irrigation can be limited to the possible operational costs associated with 'safe' reuse and additional costs required to maximise crop production.

The cost of applying the waste water is in the order of $5 – 50 per megalitre depending on the amount of water captured and the pumping and irrigation systems. The nutrient content of the waste water can be valued. The value is highly variable and may range from as little as $30 per megalitre through to and over $200 per megalitre, where the waste water contains significant quantities of plant macronutrients such as nitrogen and phosphorus. The water also has a value and can be benchmarked against the value of a clean water irrigation supply that may have a cost of $2.50 to greater than $50 per megalitre.

These data show that feedlot effluent is a valuable resource. However, it can contain significant quantities of sodium and this has the capacity to degrade soil health and plant production. Equally chloride concentrations may be high and this can cause yield reductions due to toxicities. Soil sodicity can be offset through the application of gypsum or lime. The cost of these ameliorants is in the order of $25-45 per tonne delivered and spread depending upon the farm location and its distance from a supplier. The amount of gypsum and lime required is dependant upon the amount of effluent applied, the amount of sodium it contains, the amount lost in the leaching fraction, the amount of calcium the effluent contains, and the soil physical and chemical make-up. In some situations the equivalent of three tonne of gypsum is required each year to offset the application of the waste water. The cost of this soil ameliorant can negate the fertiliser value of the waste water.

This underpins the importance of managing feed qualities to reduce sodium loads in faecal matter and feedlot waste waters. The reduction of sodium in the waste water has a positive cost benefit all of the way through the crop production system in the effluent irrigation area and sustainability of the feedlot operation.

Most effluent cannot be applied at rates that fully meet the crops water demand. This necessitates the supply of clean water to ensure that maximum crop growth is achieved. This is an added cost but it provides a key element of sustainable reuse. By maximising crop production, the capture of nutrient is maximised, as is the economic return due to increased crop yield. In turn, this reduces the potential for loss of nutrient off site (because the potential for nutrient accumulation is reduced) and this improves the environmental performance of the waste water irrigation system. This principal should be applied to all facets of the feedlot operation and indeed most agricultural enterprises.

**- IMPORTANT -**
**NOTES, HINTS AND TIPS**

- Clean water is needed for crop irrigation to maximise production and nutrient capture and minimise environmental losses.

## 10 GLOSSARY OF TERMS

| | |
|---|---|
| Adsorption | The attraction of ions or compounds to the surface of a solid. |
| Anoxic | State or presence without oxygen. |
| Biological oxidation | The chemical change of an atom, ion or molecule through the addition of oxygen by means of biological chemical reactions. |
| Chelate | A soluble organo-metal complex. Certain micronutrients are supplied as chelates, often complexed with synthetic chelating agents such as ethylene tetra-acetic acid. |
| Complexation | The chemical means of forming a large compound through combining smaller individual compounds. |
| Denitrification | Microbial process whereby nitrate is converted to nitrous oxide and nitrogen gas. |
| Mineralisation | The conversion of an element from an organic form to an inorganic state as a result of microbial decomposition. |
| Nitrification | The biological oxidation of ammonium to nitrate, predominantly by autotrophic bacteria. |
| Rhizosphere | That portion of the soil in the immediate vicinity of plant roots in which the abundance and composition of the microbial population are influenced by the presence of roots. |
| Salinity | A property expressed by the total amount of water soluble salts present in a soil horizon. |
| Volatilisation | Heat induced losses from organic material, especially common with nitrogen compounds. |

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