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Te Whare Wānaka o Aoraki

CHRISTCHURCH·NEW ZEALAND

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AN EVALUATION OF RECENT ADVANCES IN THE USE

OF ANHYDROUS AND AQUEOUS AMMONIA OVERSEAS AND

THEIR APPLICATION IN NEW ZEALAND HORTICULTURE.

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A thesis

submitted in partial fulfilment

of the requirements for the National Diploma

in Horticulture

in New Zealand.

by

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CONTENTS

LIST OF PLATES

LIST OF FIGURES

INTRODUCTION

The object of this study is to evaluate recent
advances in the use of anhydrous and aqua ammonia as
nitrogenous fertilisers, with emphasis on the prospects
and needs there are for their usage in New Zealand.
There is at present a large dependence on New Zealand
made organic and imported artificial fertilisers which
are mostly low analysis materials.   These nitrogenous
fertilisers, with their low nitrogen content, have a
high cost per pound of nitrogen.   Anhydrous and aqua ammonia
are high analysis materials whose use could prove worthwhile
in this country on the grounds of economy and practicability.
An appraisal of these prospects would appear to offer
advantages in the development of horticulture (and
agriculture) in New Zealand.

Part I deals with the aspects of nitrogen in the
soil and in plants.   This introduces the trends in nitrogenous
fertilisers and usage of the various forms, particularly
anhydrous and aqua ammonia. Also dealt with is the history
of nitrogenous fertilisers.

Part II illustrates the usage of ammonia as a fertiliser. The manufacture, use for crops, equipment and basic economics are discussed, with a view to demonstrating that anhydrous and aqua ammonia fertilisers have been shown to be both efficient and very economical fertilisers overseas.

Part III deals with the position in New Zealand. The types of nitrogen fertilisers used and the economic aspects of their usage. Prospects for anhydrous and aqua ammonia in New Zealand are looked at.

In conclusion the general findings are summarised and recommendations are made with a view to future needs in New Zealand for anhydrous and aqua ammonia. This thesis attempts to tentatively answer the question, "Is there a place for anhydrous and aqua ammonia fertiliser in New Zealand, and what action should be taken to examine this subject more closely".
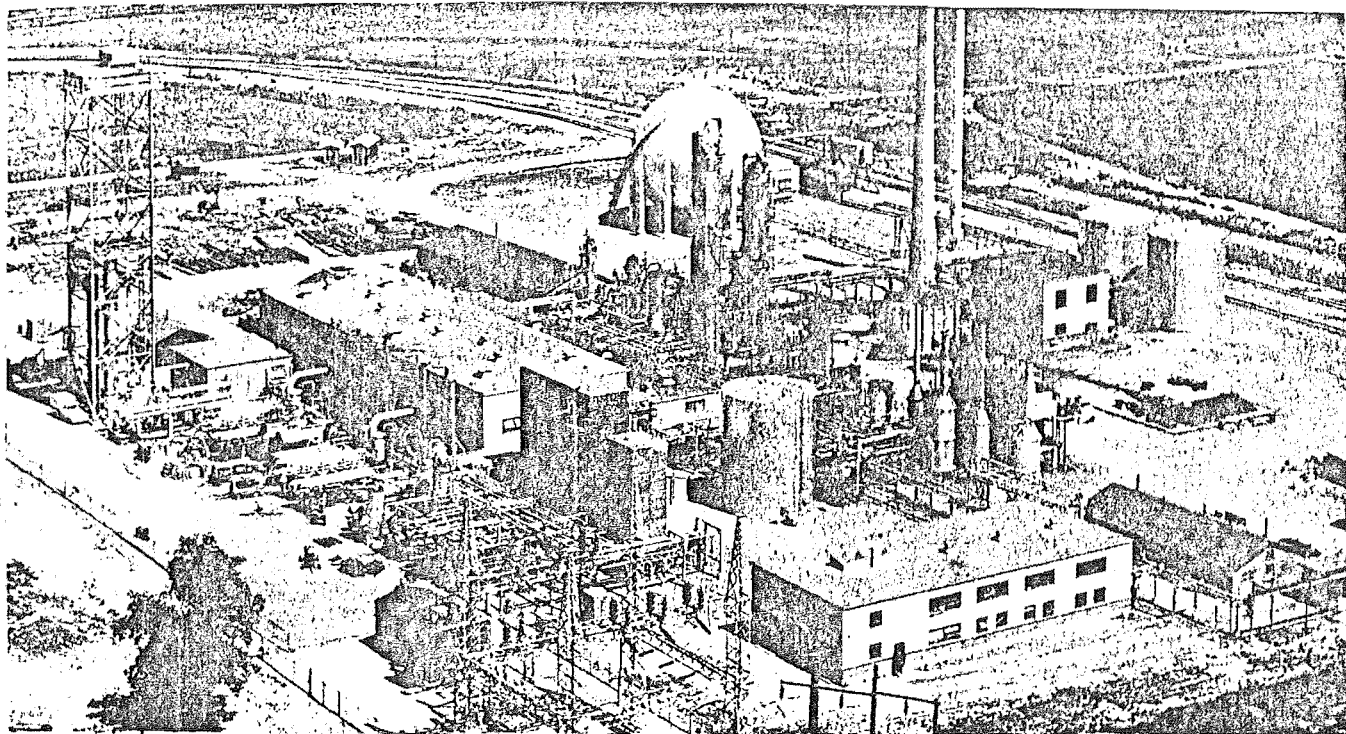
PLATE I

A typical Anhydrous Ammonia production plant where Nitrogen from the air and Hydrogen from a fuel are united to form the 82% N fertiliser.

(Reprinted from Anhydrous Ammonia Handbook) (Anon (1))

PART I

NITROGEN AND THE PLANT

PART I

CHAPTER 1

THE NEED FOR NITROGEN BY PLANTS

Research work over the years has indicated that nitrogen is the most critical food element and is in fact, a primary structural unit for all living matter. It is essential for all animal and plant protein, chlorophyll and numerous other compounds (Anon (1) 1965). This has resulted in the amount of nitrogen utilised by crops to be as great or greater than any one of the other fifteen essential elements.

Although the atmosphere contains 78% of this essential element, it is not easy for the plant to obtain a ready supply. It is important to provide nitrogen in an available form to the plant and a review of the best way to solve this and supply nitrogen in the most economical way appears necessary.

The first questions to be asked in a consideration of nitrogen metabolism are:-

    1.   What nitrogenous substances can be assimilated by plants ?

    2.   What are the pathways involved in the assimilatory process ? (Webster 1959).

There are four main sources of nitrogen in the soil:-

    1.   Organic

    2.   Ammonium

    3.   Nitrate

    4.   Molecular

Green plants obtain their nitrogen only from the soil, except in the case of legumes which make use of symbiotic nitrogen from nitrogen fixing bacteria in their roots. It is characteristic of the lower orders of plant life such as certain fungi like Endomyces and Phycomyces, various bacteria and species of unicelluar plant life like Euglena, to live solely on organic nitrogen. Other fungi like Mucor and Rhizopus and some bacteria can utilise organic and ammonium nitrogen. Certain bacteria and blue green algae can utilise all four forms of nitrogen whilst most bacteria, fungi, algae and higher plants use all but molecular nitrogen since this form of nitrogen is insoluble (Webster 1959). Although all forms, except molecular nitrogen are utilised by these higher plants with which we are mainly concerned, there is frequently a marked preference for one form of nitrogen. Many species are reported to grow better with nitrate and ammonium combined than with one alone. No plant is known to require both ions separately, but their simultaneous use avoids changes in acidity, due to preferential absorption of a single ion (McKee 1962).

For the purpose of this study it is necessary to look more closely only at the first three sources of nitrogen and their consequent metabolism for plant utilisation.

METABOLISM OF ORGANIC NITROGEN COMPOUNDS

Amino acids and urea are the main forms of organic compounds which can be absorbed by plants, most other organic compounds being poor sources of nitrogen (Webster 1959). The value of organic nitrogen substances is a function of how easily they can be broken down into ammonia, or of the efficiency with which they can be incorporated into the normal metabolic cycles of the plant.

METABOLISM OF AMMONIA

This has been studied using $^{15}NH_3$. Webster (1959) reports that this isotope was shown to be incorporated into amides, amino acids, and proteins by Vickery et al in 1940. Further experiments showed that glutamic and aspartic acids become highly labelled with ^{15}N from $^{15}NH_3$ and that glutamate, aspartate, their amides and alanine are the major products of ammonia uptake. However although ammonia is the primary material for the building of amino acids, the uptake from the soil is in general quite small in comparison with the uptake of nitrates. This is primarily because ammonia tends to be held on the soil colloids and organic matter, while nitrates which are very soluble occur mostly in the soil water.

Many species of plants, when grown in sand or solution cultures (under suitable conditions) develop as well or better when supplied with ammonium salts as when supplied with nitrates (Meyer et al 1965). This is not surprising since the nitrogen in ammonium compounds is in a highly reduced form similar to that found in amino acids and related compounds. Meyer et al goes on to say that in certain types of soils, ammonium compounds are the chief form of nitrogen which is available to plants. This is apparently true of certain soils in the northern hemisphere such as the acid podsolic soils and of many uncultivated soils in the southern areas of the United States of America. Such soils contain little nitrate, but considerable quantities of ammonium compounds and plants in these areas apparently depend on ammonium compounds for their source of nitrogen.

METABOLISM OF NITRATE NITROGEN

Nitrate is the principal form in which nitrogen is assimilated from the soil. The absorbed nitrate is rapidly reduced through the molybdenum containing enzyme, nitrate reductase (Webster 1959). Normally plants only contain relatively small amounts of nitrate as it is rapidly reduced as soon as it enters the plant. However under certain conditions plants accumulate relatively large amounts of nitrate in their tissues without any toxic effects.

Subsequently this accumulated nitrate is utilised in the nitrogen metabolism of the plant. Plants sometimes exhibit acute symptoms of nitrogen deficiency whilst they still contain quite large quantities of nitrates. Although such plants have been able to absorb nitrates, metabolic conditions within the plant have been such that they have been unable to utilise them in the formation of nitrogenous organic compounds (Meyer et al. 1965).

The first step in the utilisation of nitrates by plants is their reduction to nitrites. Plants can also use nitrites as a source of nitrogen, as shown by solution culture experiments (Meyer et al,1965). However, nitrites are seldom if ever an important source of nitrogen for plants in nature being only an intermediate stage in the reduction of nitrates. Nitrites are further reduced to ammonia, perhaps through the intermediate steps of hyponitrous acid and hydroxylamine (Meyer et al,1965).

The ammonium ions and some of the carbohydrates synthesised in the leaves are built up into amino acids mainly in the green leaf itself but some transamination does occur in roots. This source of amino acids is then built up into protein as the leaf enlarges, and this in turn produces a greater photosynthetic area for the production of more carbohydrates. The resulting nitrogen therefore not only allows conversion of carbohydrates to proteins, protoplasm and cell wall material, but also allows leaf growth. (Russell 1961).

With an ample supply of nitrogen leaves are greener and more succulent, as there is a greater proportion of protoplasm to cell wall. Excessive nitrogen can produce plants with large thin leaves which are more susceptable to attack by insects and fungi or unfavourable weather. Conversely plants grown under low nitrogen conditions tend to be paler and small, the leaf cells are small and thick walled and the leaves in consequence are harsh and fibrous.

Crops grown for their carbohydrate content such as root crops and cereals, benefit from the effect of a greater leaf area. On the other hand leafy crops like cabbages and lettuce respond directly, and have a high nitrogen requirement.

Examples of nutrient requirements for various crops indicate that nitrogen in general is needed in quite large amounts (Minard 1964).

Crop	Yield per Acre	Nutrients removed in lbs. element per acre		
		N	P	K
Early potatoes	7 tons	76	12	105
Carrots	12 "	107	20	105
Celery	8 "	116	20	149
Onions	12 "	71	16	60
Cauliflower	20 "	178	31	185
Savoy cabbage	14 "	223	33	185
Lettuces	10 "	47	8	89
Tomatoes	16 "	98	12	119
Spinach	8 "	85	14	74
Rhubarb	28 "	228	64	334

Many young plants tend to absorb ammonium nitrogen preferentially over nitrate nitrogen (Murphy and Schrader 1965). This phenomenon is due in part to the fact that young plants do not possess the enzyme systems necessary to convert nitrate nitrogen to the ammonium form. Azaleas, laurel, and other plants that require a low-lime soil are examples of plants which readily absorb ammonium compounds. Some plants such as lowland rice even prefer ammonium compounds to nitrates.

Allison (1966) states that ammonia is regularly found in plants but accumulates appreciably only where lack of carbohydrates delays assimilation. Both ammonia and hydrocyanic acid gasses have been identified, but the loss of ammonia as a gas is probably not great as it is not formed in large amounts and may be absorbed back into the soil.

Nitrogen has been shown to be of major importance for plants and to be essential for the building up of plant protoplasm. Increasing knowledge about crop requirements and forms in which nitrogen occurs in the soil has led to greater world-wide usage of nitrogenous fertilisers.

Crop plants mostly obtain their nitrogen in the form of nitrates, but owing to high solubility, nitrates are easily leached from soil. It is therefore important to recognise the form in which the nitrogen fertiliser is applied since it will have a bearing on plant uptake and loss from the soil. These factors

are mostly controlled by soil conditions which lead to
differing reactions.   An understanding of the nitrogen
balance in soil will therefore assist in deciding the
appropriate nitrogen fertiliser and this is commented on
in the next chapter.

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CHAPTER 2

ASPECTS OF THE BEHAVIOUR OF NITROGEN IN THE SOIL

THE NITROGEN BALANCE

Under virgin conditions in temperate soils, the nitrogen
content approaches an equlibrium value, the magnitude of which
depends primarily upon climate, vegetation and the physical
characteristics of the soil (Ensminger L.E. and Pearson R.W.1950).
However as soon as land is cultivated a new set of conditions
is established and the equlibrium level of soil nitrogen drops
much lower.   Soil nitrogen is in a dynamic state since there is
continual interchange in and out of, and within the soil of the
various forms of nitrogen.   This series of reactions is collectively
known as the "Nitrogen Cycle" (as depicted in Fig.I.)

ORGANIC NITROGEN IN THE SOIL

As described in Chapter 1, organic nitrogen is one of the
principal reservoirs of nitrogen in the soil.   The organic matter
in the soil consists of plant and animal remains which are in
varying stages of decay.   Organic nitrogen is an important factor
in fertility of a soil since it affects physical and chemical
properties.   Decomposition of organic nitrogen in soil produces
humus.

Humus

Nitrogen in humus is mostly combined with lignin-type

NITROGEN CYCLE
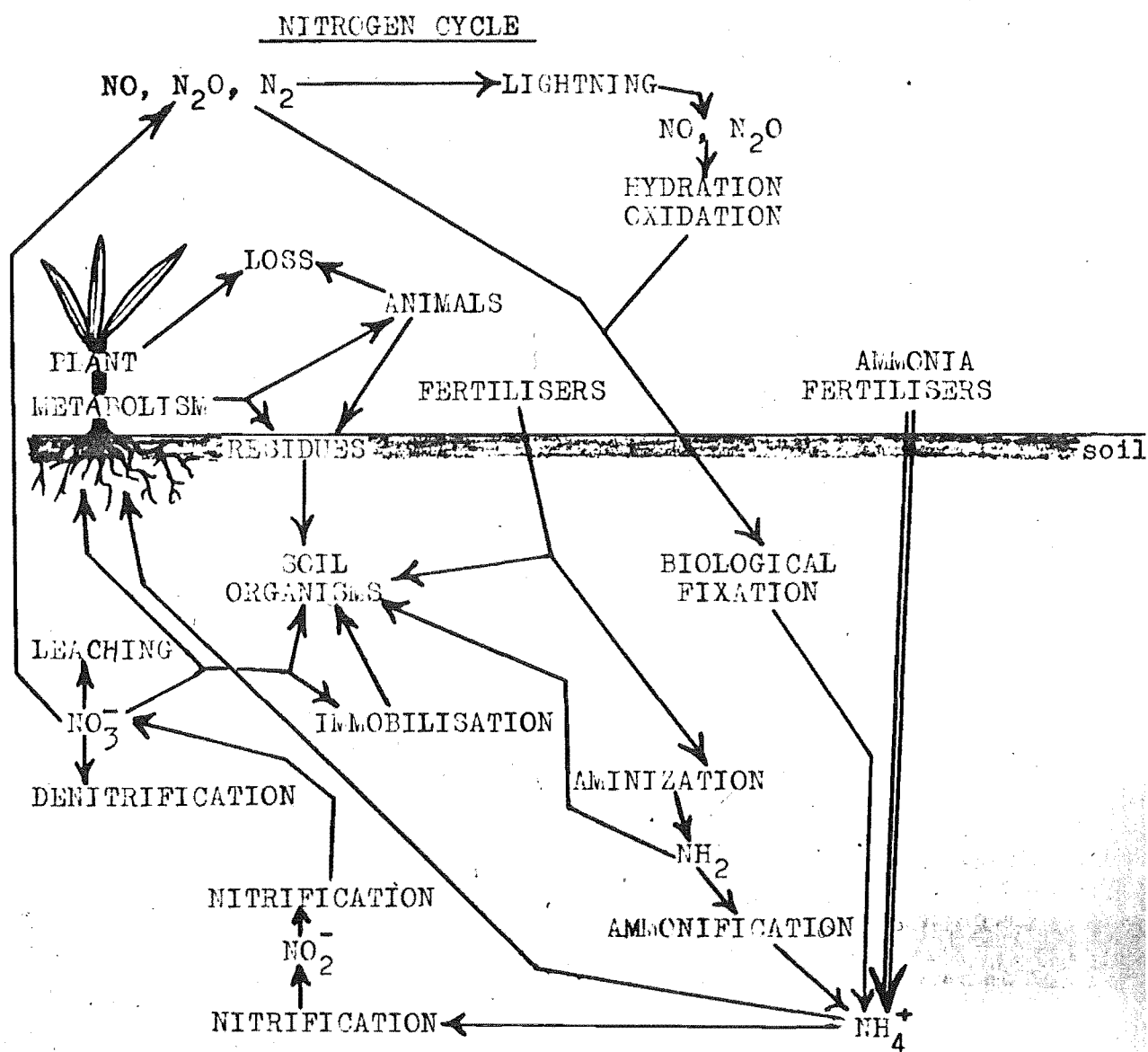
Figure I.

residues in the form of lignin protein complexes. Newly synthesised

humus bears little or no resemblance to the original organic

matter source, and it consists mostly of remains and by-products

of micro-organisms. Humus is a dark amorphous colloidal material.

It has a high capacity to absorb water and cations, and forms

stable complexes with metal ions and also with clays. It is thus

important in initial fixing of ammonia when added to soil as a

fertiliser. Humus confers a low plasticity to clay soils and

improves water holding capacity of clay and sandy soils. Humus

has a high cation exchange capacity which gives it important

buffering powers, thus the content of humus will help reduce the

effect of adding strongly alkaline fertilisers like ammonia.

Nitrogen in organic compounds, such as amino acids and

proteins, is subject to complex changes as it is broken down to

humus by micro-organisms. Proteins are converted into various

decomposition products and finally some of the nitrogen appears

in the nitrate form. Even then it is allowed no rest, as it is

either used by micro-organisms and higher plants, or is removed

in drainage, or is lost by volatilisation. Nitrogen in the soil

is in a continual state of flux. The mobility of nitrogen is very

great, rivalling carbon in its ease of movement (Buckman and

Brady 1964).

The overall process of mineralisation, which is conversion

of organic nitrogen to nitrate nitrogen, can be divided into two

parts, ammonification and nitrification.

Ammonification

This is the process in which organic nitrogen is broken down by heterotrophic bacteria, and as depicted in the diagram of the nitrogen cycle (Fig.1), it provides a natural source of ammonium ions. Ammonification is of importance here as it provides a means for release of nitrogen which has been locked up by immobilisation of nitrates.

Nitrification

Nitrification is the conversion of ammonium ions to nitrate, the most highly oxidised form of nitrogen in soil. Murphy and Schrader (1965) state that there are eight possible nitrogen compounds between ammonium and nitrate in the nitrification process, since ammonium has to lose eight electrons. The main recognised intermediate is nitrite. The oxidation of ammonium to nitrite is quite separate from that of nitrite to nitrates since a different set of micro-organisms is involved in each case. The bacteria responsible for the oxidation of ammonium to nitrite belong to the genera Nitrococcus spp. and Nitrisomonas spp. These micro-organisms are tolerant of high pH's and free ammonia. Nitrobacter spp.are autotrophic bacteria which oxidise the nitrite and are much more sensitive to high pH's and free ammonia in soil. The oxidation of nitrite to nitrate usually occurs at a faster rate than ammonium ions to nitrite but an accumulation of sizeable amounts of ammonia in alkaline soils will tend to limit the action

of the Nitrobacter spp. and sometimes cause a nitrite build-up.
Although nitrite can be readily utilised by many micro-organisms
it is very toxic to higher plants when present in the soil in
high concentrations. Nitrite can also combine with the soil
organic fraction to form stable organic nitrogen complexes and
various nitrogen gases. These nitrogen gases are often toxic to
growing tissues and in addition are a possible mechanism of
nitrogen loss to the atmosphere.

Non-Symbiotic Nitrogen Fixation

Non-symbiotic nitrogen fixation is carried out by algae,
fungi and bacteria. This is supplemented by ammonia added in
rainfall which amounts to approximately five pounds per year,
per acre on average in New Zealand. Addition of non-symbiotic
nitrogen is of the greatest importance where there are low organic
matter levels in the soil. This process is often described as
Azofication, because a major part of the fixation is due to the
Azotabacter group of bacteria (Buckman and Brady 1964).

These organisms are not directly associated with higher
plants and obtain their nitrogen from the air while using soil
organic matter as a source of energy. The amount of nitrogen put
into soil by this free fixation process is dependent on such
factors as the supply of readily available energy material, supply
of available nitrogen and pH. In soils high in available
nitrogen little or no nitrogen is added by this means (Ensminger
and Pearson, 1950).

Symbiotic Nitrogen Fixation

The accumulation of nitrogen in New Zealand soil due to its predominantly pastoral mode of farming is greatly dependent on symbiotic nitrogen fixation. Rhizobia bacteria in the nodules of legumes are able to fix atmospheric nitrogen. Symbiotic fixation of nitrogen is dependent on factors such as aeration, available nitrogen, moisture and the amount of active calcium in the soil (Ensminger and Pearson, 1950). Other factors such as the need for molybdenum and the strain of Rhizobium are also important.

Buckman and Brady (1964) state that nitrogen fixed by nodule organisms can go in three directions. Firstly it can be absorbed and utilised by the host plant. Secondly the nitrogen can pass into the soil itself, either by excretion or more probably by a sloughing off of the roots and especially of their nodules. The crop growing in association with the legume may therefore benefit, as in a pasture with clover and grass. Lastly, when the land is ploughed and the legume is turned over, nitrogen will be released when decomposition occurs. Since these residues usually have a low carbon-nitrogen ratio their nitrogen may swing through the nitrogen cycle with remarkable ease and may quickly appear in the ammoniacal and nitrate forms.

Symbiotic nitrogen fixation has less significance in cropping soils. The incorporation of legumes in a rotation has long been a recognised practice in growing vegetables. However with

specialised growing procedures it is often not economic to grow
a legume on the land with much regularity, and nitrogen is then
applied in the form of fertilisers.   Continual cropping will
tend to deplete organic matter in the soil and there is usually
quite heavy demands on the nitrogen supply as well as other
nutrients. Decline of soil nitrogen ih cropping soils can also
be accounted for by crop removal and erosion and by other factors,
which are examined in the following chapter.

CAUSES OF LOSS OR SHORTAGE OF NITROGEN IN THE SOIL

Leaching

Leaching is the downward movement and consequent loss of
nutrients in soil drainage water. Leaching is the main source of
nitrogen loss in field soils and is nearly all as nitrate, while
loss of ammoniacal nitrogen in this way is small (Allison, 1966).
When rainfall is sufficient nitrate in upper horizons of the soil
is diluted and moves to lower regions.

Burns and Dean (1964) state that there are many factors
affecting loss of nitrate by leaching in soil. The most important
of these are:-

1. Soil porosity.

2. Amount and movement of water.

3. Cations associated with the nitrate radicle.

4. Physical placement.

5. Amount of nitrogen added.

6. Temperature.

7. Microbial activity.

Loss of nitrates in soil drainage water has an important bearing on anhydrous ammonia application since anhydrous ammonia will undergo nitrification when applied when the soil temperature is above 55^OF. This renders the nitrogen susceptible to leaching in the form of nitrate. On the other hand, if nitrogen is applied as ammonia in late autumn or winter, little or no nitrogen is converted to nitrate due to low temperatures, and, as a result there is less leaching of nitrogen. Leaching is a greater problem in light soils and in high rainfall areas.

Loss by Denitrification

Denitrification is the biological reduction of nitrite and nitrate. Both of these radicles are changed to gaseous products such as nitrous oxide or molecular nitrogen. There is a resulting reduction in the overall nitrogen content in the immediate environment of the denitrifying organisms. Ammonia as such cannot undergo the process of denitrification. This process is carried out by anaerobic bacteria which generally use oxygen as a hydrogen acceptor, but may also use nitrate as substitutes (Allison, 1966). Denitrification is most likely to occur when there is a shortage of oxygen. It occurs to the greatest extent under conditions of high soil moisture, but it may also occur on finer textured soils

where moisture content is below field capacity. Under
common field conditions denitrification is probably second only
to leaching as a source of nitrogen loss in the soil. High
temperatures, low oxygen supply, waterlogged conditions and a
neutral or too high pH tend to enhance the denitrification process
(Murphy and Schrader, 1965).

Denitrification

Nitrate	Nitrite	Questionable Intermediates like Hyponitrite	Molecular Nitrogen N_2

$$NO_3 \longrightarrow NO_2 \longrightarrow \text{like Hyponitrite}$$

$$\downarrow$$

$$H_2 N_2 O_2$$

NO
Nitric Oxide
(gas)
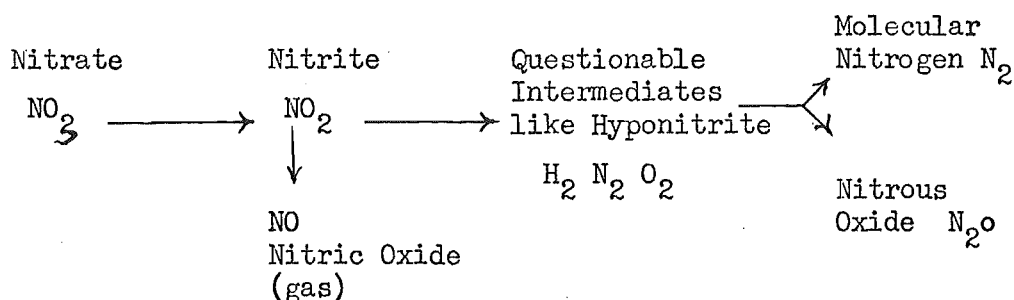
Nitrous
Oxide N_2O

Under most soil conditions nitrous oxide is the gas lost
in largest amounts. With a pH above 7 loss by elemental nitrogen
is also important and below pH 6 there are increasing amounts of
nitric oxide lost to the atmosphere (Buckman and Brady, 1964).

Loss by Ammonia Volatilisation from the soil

The loss of nitrogen from soils as ammonia is likely to be
of greater consequence than has been supposed in the past (Buckman
and Brady, 1964). This is principally due to changes in nitrogen
sources and farm practices. Allison (1966), attributes the main
causes of this increased loss (in the United States of America) to

greater use of nitrogen fertilisers, use of anhydrous and aqua

ammonia instead of ammonium salts and to the extensive use of

urea which is readily hydrolysed by urease to ammonia. Ammonia

volatilisation is of particular importance on soils low in

organic matter and clay, since ammonia is only sparingly fixed

by these soils components, and will either be given off into the

atmosphere or remain in soil water.   Loss of ammonia will also

be greater when it is not covered or sealed properly at application,

or when simply applied to the surface.

Biological Immobilisation.

Biological immobilisation affects higher plants most

significantly when there is a high carbon to nitrogen ratio and

as a result the micro-organisms in the soil take it up and convert

it to organic forms in the microbial tissue.   Murphy and Schrader

(1965) term this process "microbial denitrification". A large

supply of carbohydrates in soil represents a large food supply

and energy source to micro-organisms and under favourable conditions

a tremendous multiplication of their numbers takes place.   This

causes a temporary standstill in the nitrification process until

the supply of energy is reduced.   When this occurs the microbe

population drops and there will then be some ammoniacal nitrogen

released. When the carbon nitrogen ratio in temperate climate

soils is approximately 25, the ammonium nitrogen is converted on a

large scale into various proteins by the metabolic activities of

of micro-organisms. As the C/N ratio drops to about 15 these
organisms begin to die, and the nitrogen contained in their cells
is converted back to ammonium nitrogen by the process of
ammonification.   The addition of ammonia to soil as opposed to
bulky manures greatly reduces any possibility of a shortage of
nitrogen occuring due to biological immobilisation.

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CHAPTER 3

NITROGEN AS A FERTILISER

HISTORY OF NITROGENOUS FERTILISERS.

Since the beginning of recorded history man has sought to increase the yield of his crops by the addition of substances to the soil. Even in primitive cultures man noticed that grass grew better where animals defacated or urinated, and thus he developed simple manuring techniques. Records of ancient Chinese civilisation, as well as early Greek and Roman writings, refer to the use of animal manure to fertilise the ground (Ensminger and Pearson, 1950). Long before the birth of Christ, Egyptians applied the deposits of the Nile to their poorer lands. The early discoverers of America observed that certain Indian tribes ritually placed a fish in each planting hill with several kernels of corn (Anon (1) 1965). For the most part, these primitive practices were passed on from generation to generation. Farming was an art and there was no science attached to these practices.

About one hundred years ago, agricultural learning and procedures started moving from the alchemy of the dark ages towards the scientific approach of today. In the 1840's a German chemist, Justus von Liebig, perceived that plants grew in relation to their intake of certain chemical substances from soil and air. This was one of the most significant beginnings to the scientific approach

of supplying plant nutrients by fertilisers.   Another person
of importance in the early days was the English chemist, Humphrey
Davey, who in 1813 theorized that unproductive land must be deficient
in one or more elements of the soil and these deficiencies could be
determined by chemical analysis.   Again in the 1840's, John Bennet
Lawes, on his estate in Rothamstead, England, conducted trials to
find the major elements required by plants.   He and his associate
J.H. Gilbert, produced basic evidence that nitrogen, phosphorus and
potassium are of foremost importance in crop fertilisation (Anon
(1) 1965).

As knowledge of plant nutrient requirements was gradually
built up, materials containing these elements were used by farmers
to improve their crops.   Bulky animal manures and crop refuse were
first used.   Following this, minerals were mined in order to
utilise natural supplies of potash, phosphate and nitrogen to
fertilise the ground.   Salt petre from deposits in India and nitrate
of soda from extensive fields in Chile were used as nitrogen
fertilisers.

In spite of the vastness of these deposits, a need was
recognised to obtain usable nitrogen compounds from the air.   Over
every square inch of soil there are about 12 pounds of this element –
about 20 million tons over every square mile.   Yet this is uncombined,
and insoluble, nitrogen which is not available to plants (Anon (1) 196!

The discovery and process of the manufacture of ammonia from

the air is described in Part 2, Chapter 1, under the title of
Manufacture of Ammonia.   The development of large scale ammonia
production started a new era, as ammonia is the primary or raw
material for the manufacture of a large number of fertilisers.
It is thus used in the production of ammonium nitrate, sodium
nitrate, nitrophosphates, sulphate of ammonia, ammonium sulphates,
urea, nitrogen solutions and aqua ammonia.   The use of these and
other artificial nitrogen fertilisers has increased steadily,
while usage of bulky manures has decreased, except in intensive
growing of crops such as in horticulture.

NITROGEN MATERIALS

Natural organic materials like animal manures and composts
supplied about 90% of the American domestic consumption of
commercial fertiliser nitrogen in 1900, but less than 2% in 1956.
After 1940, a year in which by-product ammonium sulphate and
Chilean nitrate together furnished about 60% of fertiliser nitrogen,
synthetic ammonia products rapidly gained dominance;   they accounted
for about 87% (1,685,000 short tons) of fertiliser nitrogen in
1955-56 (Jacob,1959).   The use of organic fertilisers like blood
and bone is still prominent in New Zealand and this is discussed in
Part 3.

Ammonium Sulphate

Ammonium sulphate in the United States of America was first
made from ammonia which came from by-product sources, chiefly coke
ovens.   In 1945 more than 90% of its manufacture was from coke ovens

but by 1957 it had dropped to 47% and manufacture from synthetic

ammonia has increased correspondingly. Spent waste and reclaimed

acids from various industrial operations are also used for a large

amount of the ammonium sulphate manufactured from synthetic ammonia.

As with other fertiliser materials, resistance to caking in storage

and ease of application in the field are important requirements

of ammonium sulphate, both of which may be markedly influenced

by the size and shape of the crystals.

Ammonium sulphate continued until 1959-1960 as the largest

single nitrogen material produced in the world (Nelson, 1965).

It is still the leading source of nitrogen in Asia, Africa, Oceania,

but in Europe and North and Central America it has been replaced

by ammonium nitrate which has a higher nitrogen content.

Approximately one third of the total nitrogen output of Russia is

ammonium sulphate, compared with about two thirds from ammonium

nitrate. The main disadvantages of ammonium sulphate as a

fertiliser are its low N content and the acid reactions that it

produces in soils.

Nitric Acid

Nitric acid is mainly used in the production of fertilisers

by conversion into ammonium nitrate products, sodium nitrate and

other materials. It is produced by oxidation of ammonia under

pressure with the aid of a platinum - rubidium catalyst, followed

by absorption of the nitric oxides under practically the same pressure

World production of nitric acid is increasing rapidly, primarily
to meet the needs of rapid expansion in ammonium nitrate production,
(Jacob, 1959).

Fertiliser grade Ammonium nitrate.

Before the second world war use of solid ammonium nitrate
as a fertiliser was confined mostly to mixtures of ammonium nitrate
with calcium carbonate, limestone or dolomite, and to combinations
of ammonium nitrate with ammonium sulphate and potassium chloride.
In 1943, the ammonium nitrate from ordnance and industrial plants
in the United States of America and Canada became available for
use as a fertiliser but the product was initially unsuitable due
to its tendency to absorb water. Once these difficulties were
overcome, fertiliser grade ammonium nitrate (33.5%N) rapidly gained
the dominant position among the solid nitrogen materials for direct
application in the United States of America.

The most commonly used method of manufacturing ammonium
nitrate in the United States of America is by prilling or spray
granulation. The treatment of granular ordnance type materials with
a petrolatum mixture and an anticoking agent involved several problems
in the early stages of ammonium nitrate usage, and was responsible
for the Texas City explosion of 1947.

There has been a sharp increase in world production and use of
ammonium nitrate, now exceeding that of sulphate of ammonia. The
United Kingdom doubled its production in the nine years starting
1957-1958, while ammonium nitrate is the principal source of

fertiliser nitrogen in the majority of European countries with the exception of Italy, Portugal, Spain and the United Kingdom, which favour ammonium sulphate (Nelson, 1965).

Urea

Fertiliser urea is marketed as the nearly pure solid, containing approximately 45 per cent nitrogen, and as solutions with ammonia and/or ammonium nitrate, both forms of which are used in mixed fertilisers for direct application. In 1948 consumption of urea fertiliser in United States of America was 3,490 short tons and this rose to 467,359 short tons by 1966 (Harre, 1967).

Urea was initially made by hydrolysis of calcium cyanamide but it is now commonly made by the reaction of ammonia with carbon dioxide under pressure. Research has been made in the formation of complexes between urea and other materials in order to decrease the hygroscopicity of urea. Present practice in the processing of solid urea for fertiliser commonly involves its conversion into pellets by spraying a concentrated solution at elevated temperature. These conditions favour the formation of biuret, a compound which has toxic effects on some plants under certain conditions. It is formed by reaction of urea with its decomposition product isocyanic acid, but this has been reduced to less than 1 per cent in recent urea manufacture (Nelson, 1965). Biuret became a problem with foliage sprays on plants like citrus.

In New Zealand biuret content is not a problem due to the high purity of urea used.

Urea hydrolyses to ammonium carbonate in soil. The reaction being catalysed by the enzyme urease which is produced by most bacteria, actinomycetes, fungi and crop residues. Large quantities of ammonia may be evolved along with the ammonium carbonate. Nelson (1965) states that the free ammonia produced could cause plant damage and, because the pH will be raised, could inhibit nitrite oxidation.

Urea has had a rapid rise in popularity in the last decade due to its high N content, effectiveness as a nitrogen source and the substantial drop in price since 1962. Its high N content gives it a distinct advantage over ammonium sulphate. World production of urea has risen from 198,000 short tons in 1950 to 5,290,000 by 1963, and was expected to double by 1966 (Nelson, 1965).

Urea Formaldehyde Materials

These materials when correctly made, have low solubility in water and are capable of releasing nitrogen to crops over extended periods of time. Urea formaldehyde is marketed under trade names such as Nitroform, Uramite and Ureaform. Ureaform is principally used on greenhouse crops and turf, as a consituent of mixed fertiliser in the United States of America.

When properly prepared, urea formaldehyde has mole ratios ranging from 1.2 to 1.4 and then exhibits the desired characteristics of low solubility, slow release of nitrogen and high nutrient value.

Products having higher ratios behave much like urea itself, whereas the urea formaldehyde resins are of little or no value as fertilisers.

Urea formaldehyde was initially made in the United States of America in mixtures by ammoniating with an urea solution. They are now made from solid urea, a liquid concentrate and formaldehyde. A third commercially practiced method involves treating mixtures containing solid urea with a solution supplying formaldehyde and free ammonia.

Urea formaldehyde has been used mostly in United States of America, however it is manufactured in France and Russia. A reported 15,000 short tons were used in the United States of America during 1961, largely in speciality lawn, garden and turf fertilisers (Nelson, 1965).

Nitrogen Solutions

Nitrogen solutions are those materials (other than anhydrous and pure aqua ammonia) that are liquid fertilisers with nitrogen as their main constituent. Examples of those used in the United States of America are as follows (Adams et al, 1965) :-

Non Pressure Solutions	Total N %
Aqueous solutions of nitrogen products	8.5 to 37.6
Low Pressure Solutions	
Ammonia / ammonium nitrate solutions	31.8 to 44.8
Ammonia / urea solution	21.0
Ammonia / ammonium nitrate / urea solutions	36.9 to 44.0

In 1961 – 62 these solutions accounted for 38 per cent of the domestic consumption of liquid fertilisers in the United States and six per cent of the nitrogen materials used directly (Adams et al, 1965).

Nitrogen solutions require simpler storage and application equipment than anhydrous ammonia, since it does not have to meet high pressure requirements. The most common solutions are those containing ammonium nitrate or urea or both, and all are generally of a lower price per unit of nitrogen than solid forms of similar nitrogenous fertilisers. In 1957 the number of nitrogen solutions available in the United States of America was 53, but by 1960 the number had increased to 99. (Adams et al, 1965).

Low pressure solutions are characterised by the presence of free ammonia, 4.3 to 49 per cent by weight. They are used principally for the manufacture of mixed fertilisers, but also have a use in direct application. Non-pressure solutions are principally used for direct application. Choice of a solution for a particular purpose and area involves, among other things, consideration of its vapour pressure and salting-out temperature. The vapour pressure varies from a gauge pressure of 3 psi with the lowest low pressure solution to 144 psi with the highest pressure solution at $104^{O}F$. (Adams et al, 1965).

The salting out temperature is the temperature at which crystals begin to form in the liquid and this will cause equipment

failure.   Solutions with high salting-out temperatures cannot be recommended for use during cold weather unless they are diluted to prevent salting-out.

Nitrogen solutions are corrosive, particularly when they contain ammonium nitrate. Aluminium equipment is preferred but addition of ammonium thiocyanate as a corrosion inhibitor will permit use of carbon steel (Nelson, 1965).

Custom or contract application is a major factor in distribution of nitrogen solutions in the United States of America. Many American farmers, because of high cost of machinery and labour, prefer to have the materials custom applied rather than invest in labour and application equipment.

FERTILISER DEVELOPMENTS IN THE UNITED STATES OF AMERICA.

The importance with which nitrogenous fertilisers have come to be regarded can be illustrated by reference to statistics from the United States of America (De Geus, 1967):-

Year	Short tons of elements used as fertilisers		
	N	P	K
1935 - 39	371,236	287,820	311,313
1960 - 61	3,030,788	1,163,837	1,799,882
1964 - 65	4,605,442	1,552,832	2,347,620

Although fertiliser usage has risen generally, there is a very strong swing towards increased use of nitrogen fertilisers. This is illustrated by the relative amounts of N : P : K used, which have changed from 1 : 1 : 1 in 1935 - 39 to roughly 9 : 3 : 5

in 1964-65 in America. The expectations for plant nutrient consumption by 1980 in the United States of America, which were made by the Tennessee Valley Authority, are:-

Nitrogen	10,000,000 tons (N)
Phosphorus	2,262,000 tons (P)
Potash	4,482,000 tons (K)

Harre (1967) described the usage of nitrogen in the United States of America as follows:-

"Nitrogen consumption in the United States increased to 5,326,303 short tons in 1966 from 4,638,538 in 1965, an increase of 14.8 per cent. Nitrogen now accounts for more than 43 per cent of all plant nutrients used and is expected to increase to 46 per cent by 1970. Direct application materials were almost 70 per cent of the 1966 total, a jump from 68.7 per cent in 1965. (This increase is depicted in Figure II).

Anhydrous ammonia for direct application continued its rapid growth with a 25.3 per cent increase in 1966. This material now represents 43 per cent of all direct application materials used. Use of nitrogen solutions increased 19.6 per cent and aqua ammonia 22 per cent.

The use of solid nitrogen materials for direct application increased at a slower rate, with solid ammonium nitrate showing a 12 per cent increase and solid urea 9 per cent. Urea now

accounts for 17 per cent of the solid direct application

nitrogen market, compared with 6 per cent in 1956."

I.   Table of usage of nitrogen fertiliser in the U.S.A. 1964-65
(De Geus, 1967)

	Short tons N.	Percentage of total
Mixtures	1,456,866	31.6
Anhydrous ammonia	1,268,686	27.5
Nitrogen solutions	592,216	12.9
Aqua ammonia	146,874	3.2
Ammonium nitrate	550,207	11.9
Ammonium nitrate limestone	35,294	0.8
Ammonium sulphate	161,848	3.5
Ammonium phosphates	111,778	2.4
Sodium nitrate	48,575	1.1
Urea	193,713	4.2
Natural organics	18,511	0.4
Other nitrogen materials	20,841	0.5
Total	4,605,442	100.0

Thus recent years have seen a marked revolution in the

nitrogen fertiliser industry.   Changes in the United States of

America have occurred not so much from the introduction of new

materials (anhydrous ammonia was used commercially in the mid-1930's)

but in greatly expanded production and consumption, the changing

importance of the different nitrogen materials, sources used in

NITROGEN CONSUMPTION
UNITED STATES

MILLION TONS OF N

TOTAL

DIRECT APPLICATION

MIXTURES

1950 1955 1960 1965
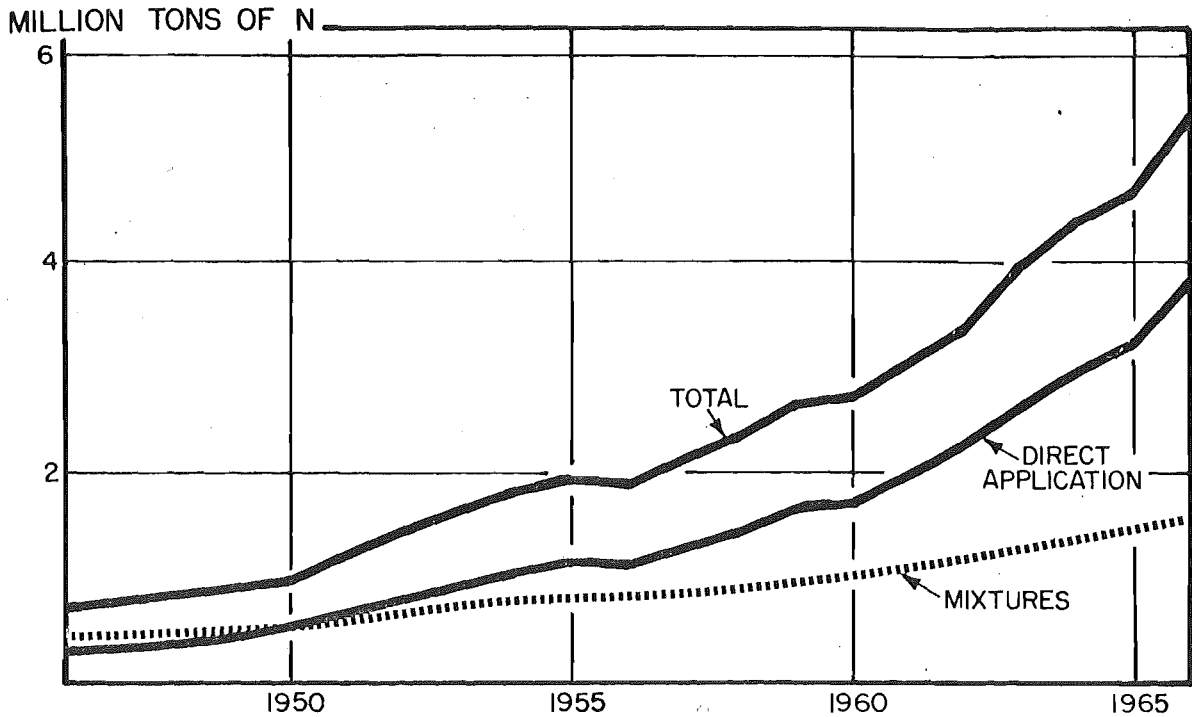
Figure II.

CONSUMPTION OF NITROGEN
AS STRAIGHT MATERIALS
UNITED STATES

MILLION TONS OF N

ANHYDROUS AMMONIA

NITROGEN SOLUTIONS

SOLID AMMONIUM NITRATE

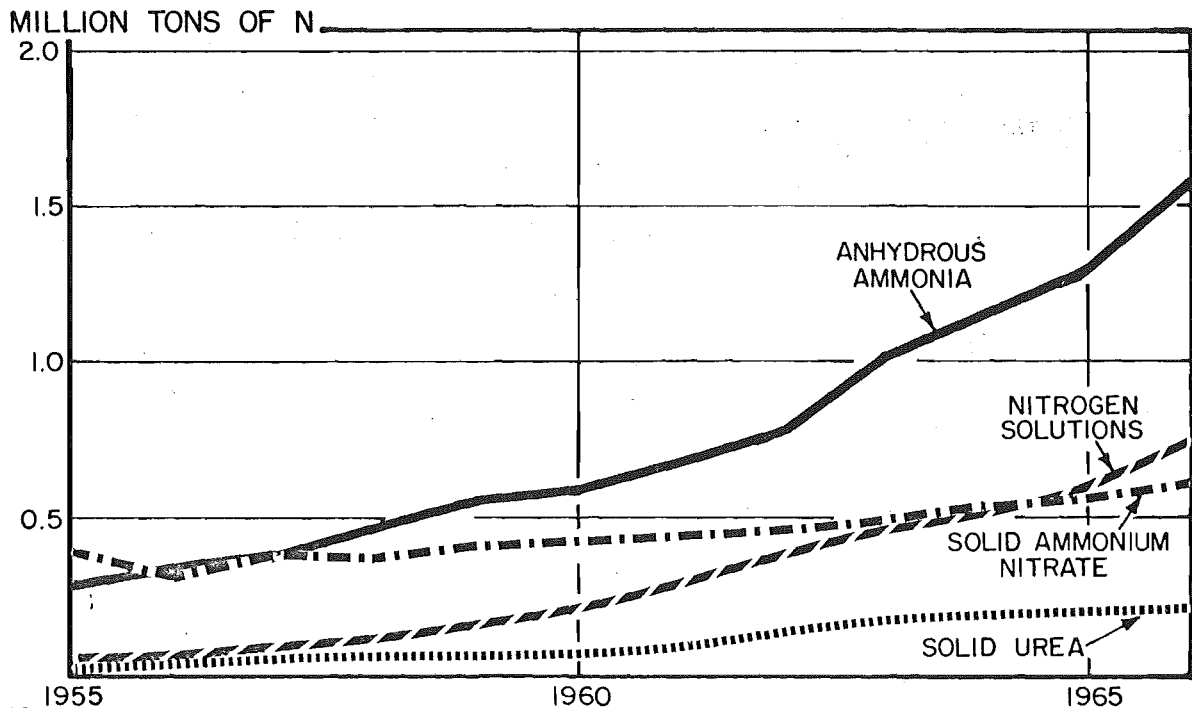SOLID UREA

1955 1960 1965

Figure III

manufacture, and in improvements of manufacturing processes.

Whilst anhydrous ammonia has increased in importance in America,

it is still largely unused in other countries. Thus the nitrogen

industry is expanding rapidly with the greatest advance in the

United States of America. According to Nelson (1965), world

consumption of nitrogen can be expected to double between 1960

and 1970, the percentage increase being in the nutritionally

deficient countries.

Recent Developments in the Use of Anhydrous and Aqua Ammonia.

The following figures demonstrate the great increase in use

of the principal nitrogenous fertilisers for direct application in

the United States of America (Harre, 1967):-

Material	1955	N in short tons % of total	1966	% of total
Anhydrous ammonia	290,337	25.1	1,606,872	43.0
Nitrogen solutions	38,362	3.3	712,445	19.1
Ammonium nitrate	375,318	32.5	610,715	16.4
Urea	30,973	2.6	211,615	5.7
Aqua Ammonia	46,617	4.0	200,814	5.4
Other materials	375,388	32.5	391,915	10.4
Total	1,156,995	100.0	3,734,376	100.0

From the table above and Figure III it can be seen that

anhydrous ammonia in the United States of America is now the major

nitrogen fertiliser having risen from 25 to 43 per cent of all

direct application materials used. Furthermore the use of anhydrous

ammonia appears to be increasing faster than other nitrogenous fertilisers. The use of aqua ammonia is also increasing although overall consumption is not nearly as great as anhydrous ammonia. Figure III also demonstrates trends in the United States of America of the use of liquid and gaseous nitrogen materials.

Anhydrous ammonia has also been used in several European countries, in particular France, and Denmark where anhydrous ammonia comprises 2% and 20% of nitrogen fertilisers used respectively. The English farmer is now generally accepting anhydrous ammonia and there are now many firms doing contract work in England and other parts of the British Isles. Van Burg (1967) states that in 1964 East Germany applied 0.6 per cent of its nitrogen as ammonia and Czechoslovakia 3.5 per cent in 1963.

Landy (1968) reports that interest in anhydrous ammonia generally is growing considerably in Australia. At the moment most of the usage is confined to New South Wales and Queensland, while there is some use on a limited scale in both Victoria and Western Australia. Aqua ammonia has been used for several years on sugar cane in Queensland. Anhydrous ammonia has been used on a range of crops which will be discussed in Part II, Chapter 5.

PART II

ANHYDROUS AND AQUA AMMONIA AS A NITROGENOUS FERTILISER

CHAPTER 1

MANUFACTURE OF AMMONIA

In Part I it has been shown that nitrogen has become, and
is still becoming an element of major importance for crop yield
improvement. Its importance has led to new developments in
efficiency of application of nitrogen and the new techniques using
anhydrous and aqua ammonia have come into prominence over the last
decade. The use of these materials is dependent upon the effective
production of the basic constituent, ammonia. Therefore an
appraisal of this material now becomes necessary.

Extensive commercial manufacture of ammonia has been
achieved by only three of the numerous methods that have been
proposed for chemical fixation of atmospheric nitrogen and these are:-

      1.   The electric arc process.

      2.   The cyanamide process.

      3.   The synthetic ammonia process.

1. The Arc Process.

The arc process involving the direct union of nitrogen and
oxygen to form nitrogen oxides was first used on a commercial scale
in Norway in 1905 (Jacob, 1959). However this process did not prove
economic and it was abandoned in 1939. Study has continued, however,
of methods for directly combining nitrogen and oxygen, especially
as regards replacement of the electric arc by other sources of heat.

Recent sources of heat which have been investigated are solar heat and the use of nuclear energy.

2. Cyanamide Process.

The cyanamide process was first begun in about 1906 and has been mostly confined to Europe and Japan. Nitrogen is fixed by reaction with calcium cyanamide (Jacob, 1959). Production in the western hemisphere is largely restricted to a large plant situated in Canada.

3. Synthetic Ammonia or Haber-Bosch Process.

The first large scale plant for manufacture of ammonia by the union of nitrogen with hydrogen at elevated temperature and pressure was established at Oppau in Germany in 1913. A scientist named Fritz Haber managed to synthesize small amounts of ammonia in his laboratory by forcing nitrogen to combine with hydrogen. A chemical engineer called Carl Bosch, then developed facilities for mass production of ammonia. This method has since become known as the Haber-Bosch process after these two men who developed it. The process involves the presence of a catalyst and marked the beginning of a commercial process that now furnishes most of the world supply of fertiliser nitrogen. (Jacob, 1959).

An economical source of hydrogen is a major consideration in the location of a synthetic-ammonia plant.

Hydrogen may be obtained from the following:

1. Electolysis of water.

2. By processing carbonaceous materials such as coal, wood, charcoal, petroleum, and natural gas.

3. From gases resulting as by-products of certain industries, especially coke manufacture and petroleum processing.

4. As a by-product of the electrolytic process for caustic soda and chlorine.

Much the greatest production of hydrogen for synthetic ammonia before World War II, was based on hydrogen produced from coke by the water gas reaction. By 1950 however, about 52 per cent of production was based on coke, 43 per cent on natural gas and 5 per cent on hydrogen by-products from caustic soda chloring cells. By 1957 about 69 per cent of hydrogen production was based on natural gas, 12 per cent on oil refinery gas and only 9 per cent on coke in the United States of America. Coke oven gas is an important source of hydrogen for ammonia synthesis in Europe (Jacob, 1959).

The production of ammonia can be described as the base point of the manufacture of nitrogen fertilisers. The ammonia gas is utilised in three main ways.

1. It is liquified under pressure to produce anhydrous ammonia. Anhydrous ammonia can be used on its own as a fertiliser or it can be mixed in fertilisers to form materials like ammoniated superphosphate.

2. Aqua ammonia can be produced by dissolving ammonia gas in water. Aqua ammonia can be used on its own or can be used in the manufacture of nitrogen solutions or other nitrogen carriers like urea and ammonium nitrate.

3. Another use of ammonia gas is production of other inorganic nitrogen fertilisers. For example addition of sulphuric acid to ammonia is used in the manufacture of sulphate of ammonia, while combination with phosphates produces materials such as ammonium phosphate and nitrophosphates (Buckman and Brady, 1964).

WORLD DISTRIBUTION OF AMMONIA PLANTS

The United States of America has shown the greatest rise in production of synthetic ammonia and will most likely continue this trend. The total capacity for the production of ammonia for all purposes, on the 1st January, 1967, was estimated at 12,156,000 short tons of ammonia. This figure is estimated to rise to 17,851,000 short tons of ammonia in 1968, (Harre 1967). There are approximately 100 plants for the production of synthetic ammonia in the United States alone, as can be seen in Figure IV, and the rapid rise in ammonia production is depicted in Figure V.

The importance of ammonia as a raw material has been appreciated in other countries apart from the United States of America. The following countries built plants between 1945 and 1958 – Brazil, India, Columbia, Egypt, Finland, Iceland, Israel, Mexico, Pakistan, Peru, Phillipines, Portugal, South Korea, Taiwan, Trinidad, Turkey, Venezuela and Jugoslavia.

AMMONIA PLANT LOCATIONS

△ NEW PLANT
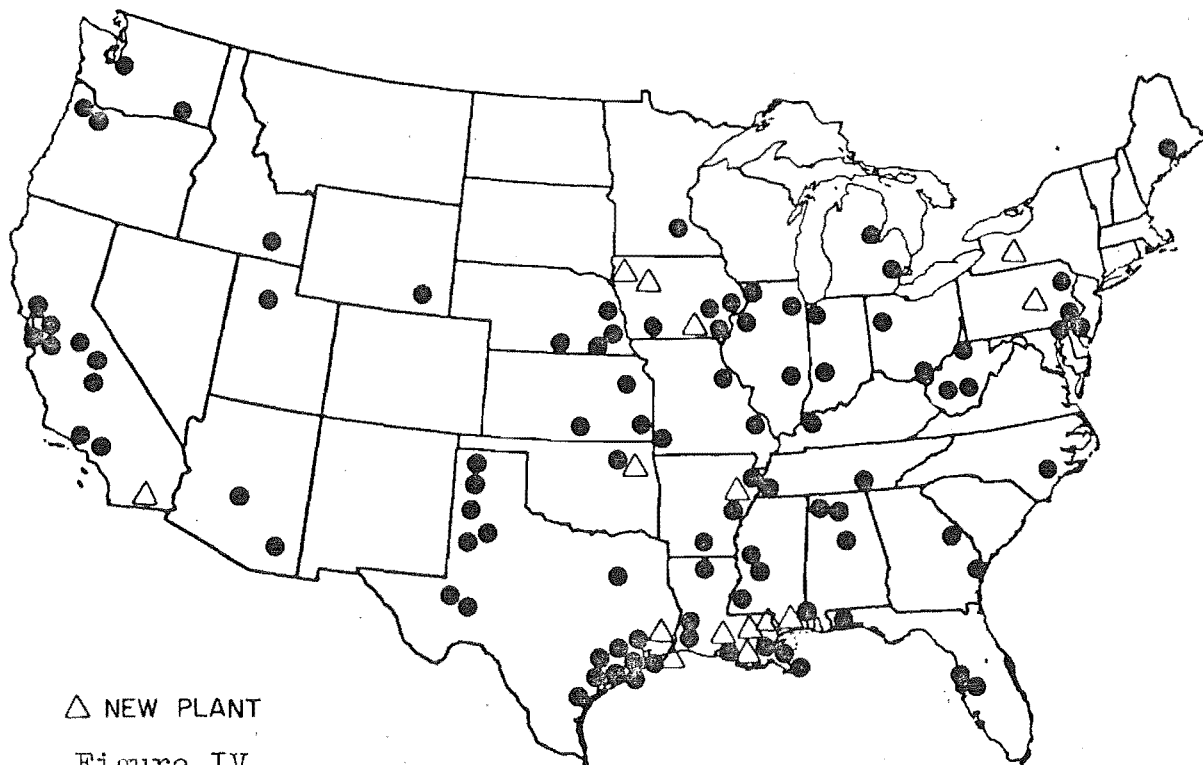
Figure IV.

ANHYDROUS AMMONIA PRODUCTION
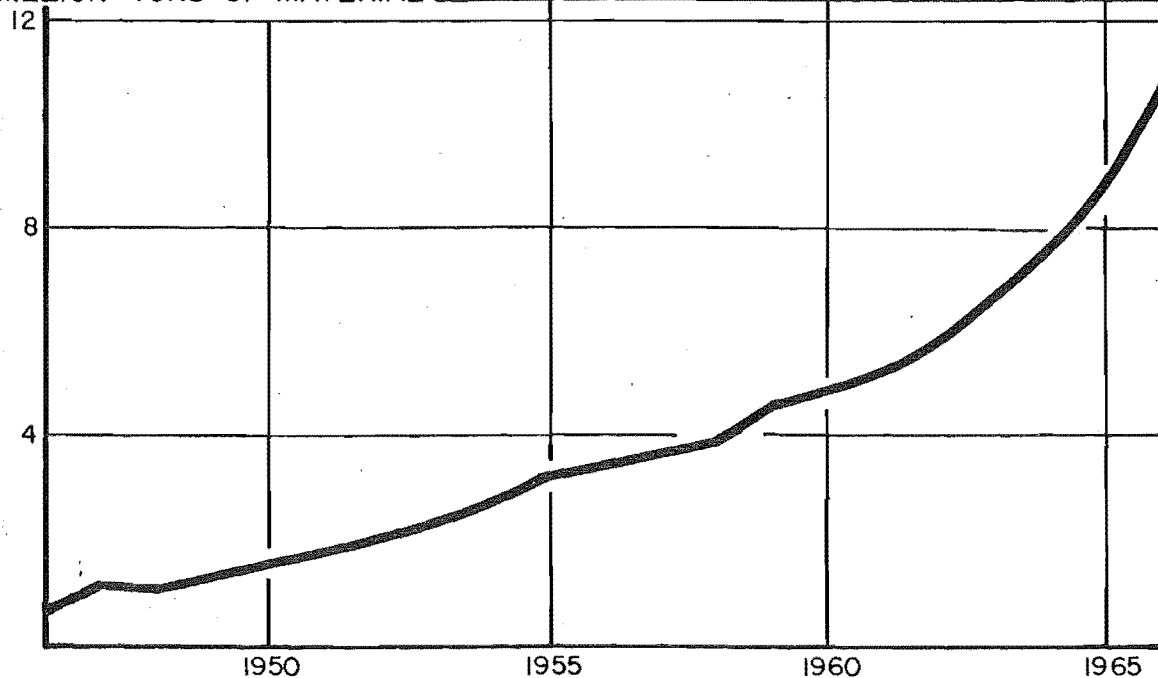### UNITED STATES

MILLION TONS OF MATERIAL

Figure V.

From 1950 to 1955 Canada was the principal supplier to the United States of nitrogen fertilisers based on synthetic ammonia. The production of nitrogen as synthetic ammonia rose from 370,000 short tons in 1939 to 1,258,000 short tons in 1947. In this time an increase from 7 to 19 plants occurred due to the impetus of the Second World War. In 1950 to 1957 there was an increase from 22 to 56 plants and the capacity rose from $1\frac{1}{2}$ million to 4 million short tons of nitrogen. The tremendous expansion of synthetic ammonia plants in the world kept growing and by 1963 there were some 278 synthetic ammonia plants in operation and another 43 were under construction. These plants accounted for over 80% of the world's production of fertiliser nitrogen. The remaining 20% was produced from coke oven gases, by the cyanamide process and a small amount from natural materials, (Nelson, 1965).

The building of synthetic ammonia plants in Australia is of particular significance to New Zealand. There are at present two plants which are fully operative, one in Sydney, which has a capacity of about 100 tons of ammonia per day, and one in Brisbane which has a 150 tons per day capacity. These were started in mid-1964 and 1966 respectively. There are also plants due to start in late 1968 in Perth, Brisbane and Newcastle with proposed capacities of 330, 600 and 600 tons per day respectively. It appears therefore that there will be a ready source of ammonia in bulk in Australia and the price should lower as production and usage increase.

In conclusion it can be seen that ammonia is largely produced by direct synthesis of elemental nitrogen and hydrogen. It is also produced in small quantities as a by-produce from coke manufacture. It is produced in New Zealand for example at the Wellington and Auckland gas works but will never be available from these sources in large enough quantities for commercial fertiliser usage. On the other hand, there are several synthetic ammonia plants in Australia.

Since most inorganic nitrogen fertilisers are manufactured from anhydrous and aqua ammonia its production is important in economic manufacture of these fertilisers as well as for direct application.

— — — — — — —

CHAPTER 2

PROPERTIES OF AMMONIA

ANHYDROUS AMMONIA

Chemical Properties

Ammonia is a compound made up of nitrogen with three parts hydrogen, i.e. NH_3. The term "anhydrous ammonia" means free of water. Anhydrous ammonia is highly soluble in water and forms aqua ammonia (ammonium hydroxide) as shown in the following equation:-

$$NH_3 + H_2O \longrightarrow NH_4OH$$

Most of the common metals are not affected by dry ammonia, but the presence of moisture will cause ammonia to react rapidly with copper, brass, zinc (galvanised equipment) and many alloys, especially those containing copper. Iron and steel are not affected by moist ammonia, and equipment made of these materials can be used with both anhydrous and aqua ammonia.

Physical Properties

Anhydrous ammonia is a liquifiable gas which is handled in commerce in a liquid form. Though its density varies with temperature, it weighs 5 pounds per gallon at $80^{o}F$. Ammonia gas is less than two thirds as heavy as air, and when released into air, rises quickly unless brought down by air currents. It has a gauge pressure of 74 psi at $50^{o}F$.

One cubic foot of liquid expands to approximately 850 cubic feet of vapour.

Boiling point at 1 atmosphere (vaporisation point)	$-28°$F.
Melting point at 1 atmosphere	$-107.9°$F.
Critical temperature	$271.4°$F.
Critical pressure	1,657 p.s.i
Vapour density at $-28°$F. 1 atmosphere	0.0555 lb/cu.ft
Liquid density at $-28°$F. 1 atmosphere	42.57 lb/cu.ft
Specific volume of vapour at $32°$F. 1 atmosphere	20.78 cu.ft/lb
Range of explosive ammonia – air mixtures	16 – 25% NH_3 by volume
Ignition temperature (iron bomb)	1.204°F.
Specific heat, (1 atmosphere 60°F)	0.52B.R.U./16/

Solubility in water at 1 atmosphere
       depends on temperature:-

$32°$F.	0.899g. NH_3/g water
$68°$F.	0.518g. NH_3/g water
$104°$F.	0.338g. NH_3/g.water
$140°$F.	0.238g. NH_3/g.water
Specific gravity of the gas (air = 1.00)	0.588
Specific gravity of the liquid (water = 1.00)	0.617
Vapour pressure at o°F.	15.7 p.s.i
Vapour pressure at 70°F.	114.1 p.s.i
Vapour pressure at 100°F	197.2 p.s.i
Vapour pressure at 130°F	315.6 p.s.i
Vapour pressure at 150°F.	418.4 p.s.i

Toxicity of Ammonia

Adams et al (1965) described the critical gaseous ammonia concentrations for humans.

II.   Table – Ammonia Toxicity

Effects on unprotected worker	Concentration parts per million	Exposure period
1. Least detectable odour	50	)
		) Permissible for
2. No adverse effects for average unprotected worker	100	)) 8 hour working day.)
3. Causes irritation of the throat	400	) Ordinarily no) serious results) following
4. Causes irritation of the eyes	700	) infrequent exposure) (less than 1 hour)
5. Causes convulsive coughing	1720	No exposure permissible (may be fatal after short exposure – less tha half an hour).
6. Causes respiratory spasm, strangulation, asphyxia	5000	No exposure permissible, rapidl fatal.

Care must be taken when handling ammonia gas for it is very soluble and will readily dissolve in the perspiration of the body (Adams et al, 1965). It can cause caustic burns which vary in severity with the length of exposure. A two per cent concentration is generally the maximum tolerated by the skin for more than a few seconds as ammonia causes freezing due to the evaporation of the liquid.

Persons working with ammonia should wear suitable protective clothing, including gas masks, rubber gloves and other rubber clothing. A person overcome or burned by ammonia should be placed under the care of a doctor. Immediate artificial respiration should be carried out if the person has been asphixiated. The symptoms resulting from exposure to ammonia gas may be nausea, vomitting, pain in the abdomen and throat, weak and rapid pulse, convulsions, burning of the eyes and coughing.

Aqua Ammonia

Aqua ammonia is a colourless liquid with the same pungent odour as anhydrous ammonia.

The general properties of aqua ammonia are listed as follows:-

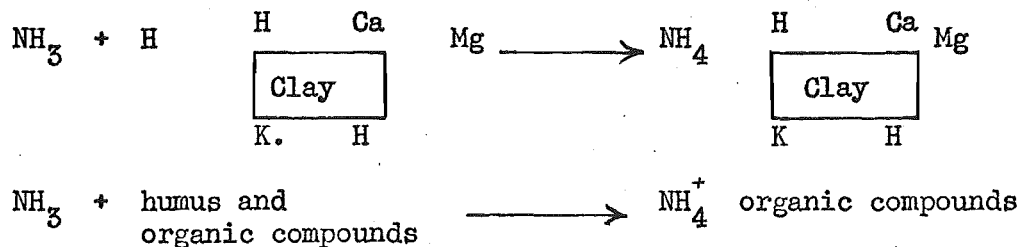|	
Ammonia content	25.0%
Nitrogen content	20.6%
Salting out temperature	103°F.
Calcium carbonate equivalent per 100 lb.material	37.1
Vapour pressure (gauge) at 60°F.	-9 p.s.i
104°F	2 p.s.i
120°F	8 p.s.i
Specific gravity at 60°F	0.911
Weight of solution per gallon at 60°F	7.60 pounds
Weight of nitrogen per gallon at 60°F	1.56 pounds
Volume per 100 pounds of nitrogen at 60°F	64.1 gallons

CHAPTER 3

BEHAVIOUR, DISTRIBUTION AND EFFECTS OF AMMONIA IN THE SOIL

Soil application of anhydrous ammonia takes advantage of
the rapid expansion of the liquid to a gas and its high affinity
for water. Several chemical processes begin as soon as ammonia
(NH_3) is injected into the soil (Murphy and Schrader, 1965):-

Firstly there is the conversion of ammonia gas into ammonium
ions (NH_4^+). In practise the liquid flows into the soil where it
is deposited at a depth of about 6 inches. On release it expands
to a gas, spreads out in the soil and dissolves immediately in
soil moisture forming ammonium hydroxide, which then dissociates
into hydroxyl and ammonium ions. :-

$$NH_3 \;+\; H_2O \longrightarrow NH4OH \longrightarrow OH^- \;+\; NH_4^+$$

| | Ammonium Hydroxide | Hydroxyl Ions | Ammonium Ions |
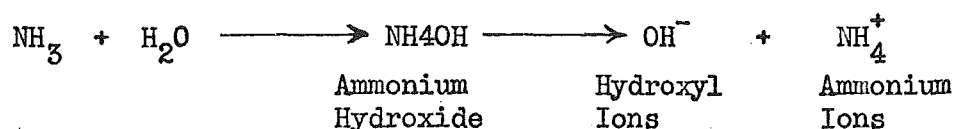
Ammonia also forms ammonium ions in contact with acid clay
particles and with humus and organic compounds:-

$$NH_3 \;+\; H \quad \boxed{\begin{array}{cc} H & Ca \\ \text{Clay} \\ K. & H \end{array}} \quad Mg \longrightarrow NH_4 \quad \boxed{\begin{array}{cc} H & Ca \\ \text{Clay} \\ K & H \end{array}} \quad Mg$$

$$NH_3 \;+\; \text{humus and organic compounds} \longrightarrow NH_4^+ \;\text{organic compounds}$$

Thus in the process of conversion from NH_3 to NH_4^+, the ammonia
molecules accept hydrogen ions (H^+) from a soil source and become

positively charged ammonium ions. The formation of ammonium ions converts ammonia gas, which is toxic to living matter, to a form which can be utilised by soil micro-organisms and higher plants.

The next process is adsorption, whereby ammonium ions, formed with the initial reactions with water, clay and organic matter attach themselves to soil mineral particles. Ammonia may be absorbed on soil colloids by a variety of reactions. The reactions are extremely important from the standpoint of fertiliser usage for two reasons:-

1. The adsorption itself prevents loss of ammonia molecules to the atmosphere and so preserves it in the soil for plant and microbial use.

2. Some of the adsorption mechanisms convert ammonia gas directly to the ammonium form.

Adsorption of ammonia occurs due to physical and chemical reactions.

1. Chemical Adsorption

This occurs when ammonium ions become bonded to clay particles due to electronegative attraction. Ammonia is converted into ammonium ions prior to, or simultaneously with chemical adsorption, since ammonia has to be in this positively charged form before bonding to the specific sites on clay particles can take place. Ammonium ions held in this way are considered to comprise the soil's exchangeable ammonium supply. Buckman and Brady (1964) state that

the ammonium ion is about the same size as the potassium ion and therefore both are subject to fixation by similar minerals. Illite and related clays have a significant ammonia fixing capacity. In this form nitrogen is not subject to rapid oxidation but may slowly become available to plant roots. Chemical reactions tend to hold ammonia very strongly and they may be represented by the following equation:-
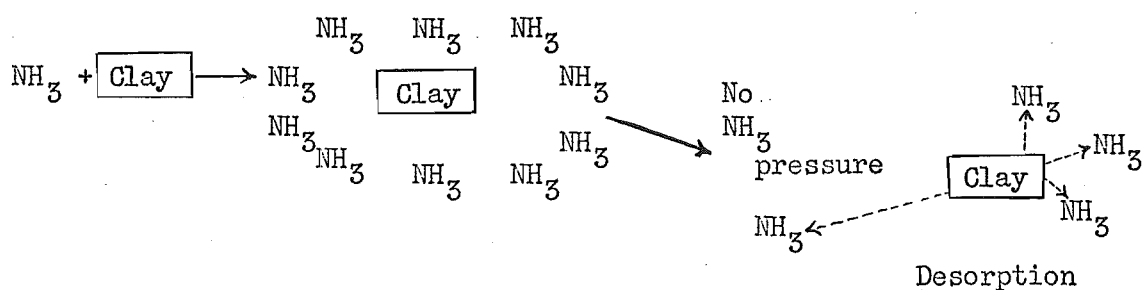
$$4NH_4^+ \quad + \quad \boxed{Clay}^- \quad \longrightarrow \quad \begin{matrix} NH_4 & & NH_4 \\ & \boxed{Clay} & \\ NH_4 & & NH_4 \end{matrix}$$

<div align="center">

Positively
charged

Negatively
charged

No charge

</div>
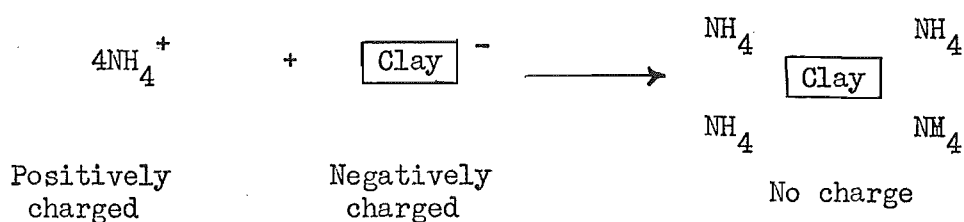
2. Physical Adsorption

Physical adsorption is characterised by weaker bonds between the ammonia and the clay, than occur in the chemical reactions. Physical adsorption takes place only where there is a positive pressure of ammonia in the soil. As soon as the pressure of ammonia in the gaseous phase is reduced, the physically adsorbed ammonia will return to the gaseous form and diffuse through the soil where it may react with soil water, clay, organic matter or perhaps volatilise into the atmosphere.

Physical Adsorption of Ammonia

$$NH_3 + \boxed{Clay} \longrightarrow \begin{matrix} & NH_3 & NH_3 & NH_3 \\ NH_3 & & & NH_3 \\ & \boxed{Clay} & & \\ NH_3 & & & NH_3 \\ & NH_3 & NH_3 & NH_3 \end{matrix}$$

No NH_3 pressure

$$\boxed{Clay}$$

Desorption

Anon (3) (1966) stated that ammonium adsorption by the soil was dependent on the following factors:-

1. Soil texture.

2. Soil structure.

3. Moisture content of the soil.

4. pH of the soil.

5. The organic content of the soil.

Soil Texture

Soils of heavier texture will have a greater capacity to hold ammonia than lighter soils, since those with more clay will have a higher cation exchange capacity and thus will have more exchange sites to hold ammonium ions. At very high rates a low cation exchange capacity could limit the ability of the soil to hold ammonia, however this does not become a problem at lower rates.

Soil Structure

Poor soil structure influences the ability of a soil to hold ammonia as it can limit the spread of gas in the soil. There will be more ammonia retained in a well-structured clay than there will be in an impervious clay since gas spreads further when soil has good tilth. The fact that ammonia can spread further in the soil brings it into contact with more cation exchange sites. However the level of exchangeable bases (Ca, Mg, Na, K.) already present determines the amount of physical and chemical adsorption which takes place.

Soil Water

Although ammonia is very soluble in water it is not essential to have a high moisture content in the soil (Anon (1) (1966). The clay and organic matter content of the soil are of much greater significance. The main problem in dry soils is holding the ammonia in the soil for the short time that is needed for it to become attached to clay or organic matter. Dry soils may be cloddy and may not seal properly, but if they are dry and in good physical structure, dry soils will actually hold more ammonia than moist soils. Anon (1966 (1)), proposes that the best soil moistness for ammonia retention in the soil is between 15 - 18% moisture content (Field capacity being 23% moisture content in clay soils).

Parr and Papendick (1966 (1), 1966 (2), 1967), carried out a series of pot trials in which they examined the adsorption of ammonia in soils of varying moisture content. They came to the conclusion that air dry and oven dry soils will hold more ammonia than soils of higher moisture content. However in the most recent trials they concluded that soil moisture content at time of ammonia application is not a critical factor in the retention of ammonia by soil, but that it is important in providing adequate physical soil conditions to insure rapid and complete closure of the injection channel.

The pH of the Soil

In theory acid soils should adsorb more ammonia than neutral soils since there are more available hydrogen ions to combine with ammonia to form ammonium ions. In practice, however, ammonia is

effectively absorbed at normal commercial rates of application even by soils containing free calcium carbonate (Anon, 1966. (1)). For conversion of ammonia in the soil in the process of nitrification, a pH of 6.5 to 7.0 is optimal for the best bacterial action (Beers, 1966).

The Organic Matter Content of the Soil.

As indicated in Part I, Chapter 2, organic matter plays a key part in the nitrogen cycle in soil. Smith & Case (1966), state that approximately 50% of ammonium ions retained in soils are contained in organic matter. This is due to the available surface area and the number of cation exchange sites being greater weight for weight in organic matter than in clay minerals. Of the ammonia adsorbed by organic matter at least 75% is in a form readily available to plants (Anon, 1966 (1)).

The Importance of Rate of Nitrification

The speed of nitrification, i.e. the time that it takes for ammoniacal nitrogen in soil to be oxidised to nitrate nitrogen has an important bearing on the application of ammonia fertilisers to soils. Nitrification is most rapid when the soil temperature is between 65 to 90°F. Outside this range micro-organisms become less active until nitrification is considered to cease when the soil temperature falls to 32°F. or below. This is made use of in America by the application of ammonia in autumn. If temperatures are low enough, nitrification will not occur during winter and thus nitrogen can be safely held in the soil ready for spring sown crops.

Nitrate nitrogen would be much more susceptable to loss from the soil (as discussed later). Nitrification is often rapid at the end of a dry summer and in warm moist conditions of spring. Conversely, nitrification will often be reduced when there are high crop residues in the soil and when it is too dry or very wet. Other factors which can affect the rate of nitrification are the supply of nutrients, particularly calcium, soil pH, soil aeration and chemical ammonium retention in soil (Murphy and Schrader, 1965).

DISTRIBUTION AND EFFECTS OF AMMONIA APPLICATION IN THE SOIL

Patterns of Distribution in the Soil.

Parr and Engibous (1965) stated:-

"It has been shown that immediately following injection of anhydrous ammonia into soil, high concentrations of ammonia and ammonium ions are retained in a localised, horizontal cylindrically shaped zone with diameter ranging from 1 to 3 inches depending on the rate of application, soil texture, soil organic matter and soil moisture."

This means that there will be an area of very high ammonia concentration which is toxic to micro-organisms in that area. As a result of this, the retention zone can remain partially sterilised for several weeks. If conditions are suitable, nitrification begins at the periphery of this area and gradually the concentration of ammonia is reduced.

Ammonia in concentrated zones in the soil will take up to eight weeks to completely nitrify under good nitrifying conditions.

Thus if conditions are optimal nitrogen remains in soil as ammonia and is not leached out as nitrates nor lost by dentrification (Beers, 1966).

Blue and Eno (1954), found that in sandy soils with rates of 58, 115 and 258 pounds per acre of ammonium nitrogen, ammonia accumulated in zones from 2 to 8 inches wide, depending on the soil moisture content. Most of the ammonia was usually concentrated in a three inch zone even at the highest rate. Papendrick and Parr, (1966), carried out detailed greenhouse pot trials which demonstrated that most of the ammonia from a single 680 mg injection of ammonium-nitrogen was subsequently found to be within a 5 cm radius around the injection point. They also found that the order of retention observed within a 3 cm radius around the injection point was:- liquid ammonia in moist soil greater than gaseous ammonia in moist soil, greater than liquid ammonia in air dry soil, greater than gaseous ammonia in air dry soil.

McIntosh and Frederick (1958), injected anhydrous ammonia by field application into sandy clay loam, at rates of 60 and 120 pounds of ammonium nitrogen per acre. In summer they found that ammonium nitrogen decreased from a maximum of 1300 to 1200 ppm. (pH 9.5) at the centre, to less than 200 ppm. (pH 8.0) in the area about $1\frac{1}{2}$ inches from the centre of the retention zone. After two weeks maximum concentration of ammonium nitrogen was 800ppm. (pH8.8) in the centre to less than 100ppm. (pH7.0) in the area about two inches away from the centre of the retention zone. Thus the high

concentration of ammonia in soil during summer application falls off quickly to low levels of ammonia nitrogen within a month. They concluded that the falling concentration is due in part to the diffusion of ammonia from the application zone, and in part to nitrification of the applied ammonia. McIntosh and Frederick, (1958) also stated that autumn applications made in America when soil temperatures are declining, will remain as ammonia until the temperature rises above 40°F. in the spring.

It is therefore important to apply anhydrous ammonia at the right depth in the soil to reduce volatilisation losses. This is particularly important in neutral and alkaline soils where it is essential to release ammonia at not less than 6 inches below the soil surface. This depth is sufficient to prevent loss to the atmosphere from the retention zone and subsequent movement out of this zone. A good understanding of the retention of ammonia in soil is important from the agronomic point of view to avoid damage to seedlings or seeds at planting and to be aware of the persistence of the retention zone so that injection will not be made too close to plants and ammonia levels will not be toxic when plant roots reach this area in the soil. Tillage of soil in close proximity to the retention zone should be avoided and injection should be carried out when the soil is in good physical condition to avoid losses, (Parr and Engibous, 1967).

Effect on Nitrification and Acidity in the Soil

Duisberg and Buehrer (1954), applied anhydrous ammonia to soil and studied the effects on nitrification and oxidation products within the plants. They found that pH showed a pronounced drop in the first few days, even though concentrations of the various forms of nitrogen remained constant. As nitrification proceeded the pH value levelled off, nitrite rose to a peak on about the tenth day and ammonia levels steadily fell whilst nitrate levels rose. The nitrification process is probably completely inhibited within the retention zone where the concentration of ammonia is usually about 30ppm. However in the field nitrification proceeds towards the centre of this area from the periphery. Therefore nitrifiers gradually reduce the concentration of ammonia centripetally until all of it is utilised. (Eno et al, 1955).

The application of ammonia to soil causes a sudden rise in pH, however as nitrification proceeds the pH value drops. The overall effect is to lower the pH of the soil. The initial rise in pH can be as high as 9.5, depending on soil type (Adams et al, 1965)

Continual use of ammonia may lower soil pH but this can be easily corrected by liming. Lowered pH has become a major problem in certain soils in the United States of America, where the pH of the subsoil has dropped rather low due to continual deep injection of ammonia.

Effect on Fungi and Micro-organisms in the Soil

Eno and Blue (1954) and Eno et al. (1955) carried out trials to study the effect of ammonia on the microbiological population in soil. Numbers of nematodes, fungi and bacteria were measured in the retention zone after a normal rate of approximately 600 ppm ammonia was applied. It was found that the nematode population was reduced to 0.6% of its original level and fungi to 4.9%. The numbers of bacteria and actinomycetes increased after a period of three days. After the first day it was found that the numbers of nematodes, fungi and bacteria were reduced, but this was only temporary in respect of the bacteria. It was also noted that toxic effects were restricted to a three inch zone around the point of injection. It was found that ammonia acted as quite a strong fungicide since the effect on fungi lasted for at least 38 days. It was concluded that from a total population standpoint these effects are not likely to permanently disturb the ecological balance in soil.

Other Effects

The application of ammonia to soil can also affect the availability of nutrients in soil. Ammonia tends to increase the availability of phosphorus and potassium in soil, while levels of readily available calcium are reduced (Stanley and Smith, 1956). However total exchangeable calcium in soil is not greatly affected and the magnitude of these effects is not very great.

In some cases nutrient release by ammonia is an unexpected

bonus in its use (Anon 1965 (1)). The presence of high concentrations of ammonia in a localised area can also cause a partial breakdown of soil organic matter for a short period after application, (McDowell and Smith, 1958). High concentrations of ammonia will inhibit seed germination and subsequent growth of plant roots in the region of high ammonia levels (Duisberg and Buehrer 1954).

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CHAPTER 4

METHOD OF APPLICATION

Application of anhydrous and aqua ammonia generally requires more complex equipment than that used for the application of other fertilisers since ammonia is mostly applied by sub-surface application. Such methods are only possible effectively, under the conditions outlined in the previous chapter, particularly with reference to texture and structure of soils. A less common but important use of anhydrous ammonia is by surface application in irrigation water. This method has gained prominence in the United States of America and in Australia.

EQUIPMENT FOR SUB-SURFACE APPLICATION

The basic ammonia application equipment consists of a high pressure tank, a metering device, a distributor manifold and injection tines. There are numerous variations on this basic design, but three main types are used: the tractor mounted, a trailing unit, and a semi-mounted unit supported by both tractor and trailing unit. Examples of applicators are shown in Plates II, III, IV and V.

Pressure Tank

There are two types of tank used overseas for the storage of anhydrous ammonia. Firstly there are non-refrigerated pressure vessels, commonly referred to as pressure tanks, where ammonia is stored at atmospheric temperature and pressure. Secondly, there

are also refrigerated tanks where ammonia is stored at relatively

low pressures. High pressure tanks are used with application

equipment and are designed for pressures of 50 psi.

They are hydrostaticly tested (in U.S.A) at time of

manufacture to about one and a half times the designed tank pressure.

Thus, a pressure tank with a designed pressure of 250 psi would be

hydrostaticly tested to 375 psi (Anon (1) 1965). All metal

equipment which comes in contact with ammonia is preferentially

made out of steel or iron. Most common metals are not affected

by ammonia, but the presence of moisture will cause ammonia to

react rapidly with copper, brass, zinc (galvanized equipment) and

many alloys, especially those containing copper (Adams, 1965).

Most tanks are cylindrical with rounded ends. On many tanks being

used for the application of these materials overseas, fittings are

screwed into threaded holes in welded-on plates which are called

"island bars". On mobile tanks mounted fittings are commonly

protected by metal guards which surround them. Basic fittings are

shown in Figure VI. These fittings are used to ensure that the

pressure and level of the liquid in the tank is fully known, and

that it can be emptied with complete safety.

Two different types of arrangement af the valves are shown in

the diagram. The bleed valves are used to remove liquid or vapour

via a hose or larger valve before disconnecting; they can also be

used to indicate when the tank has been filled to the 85% level.
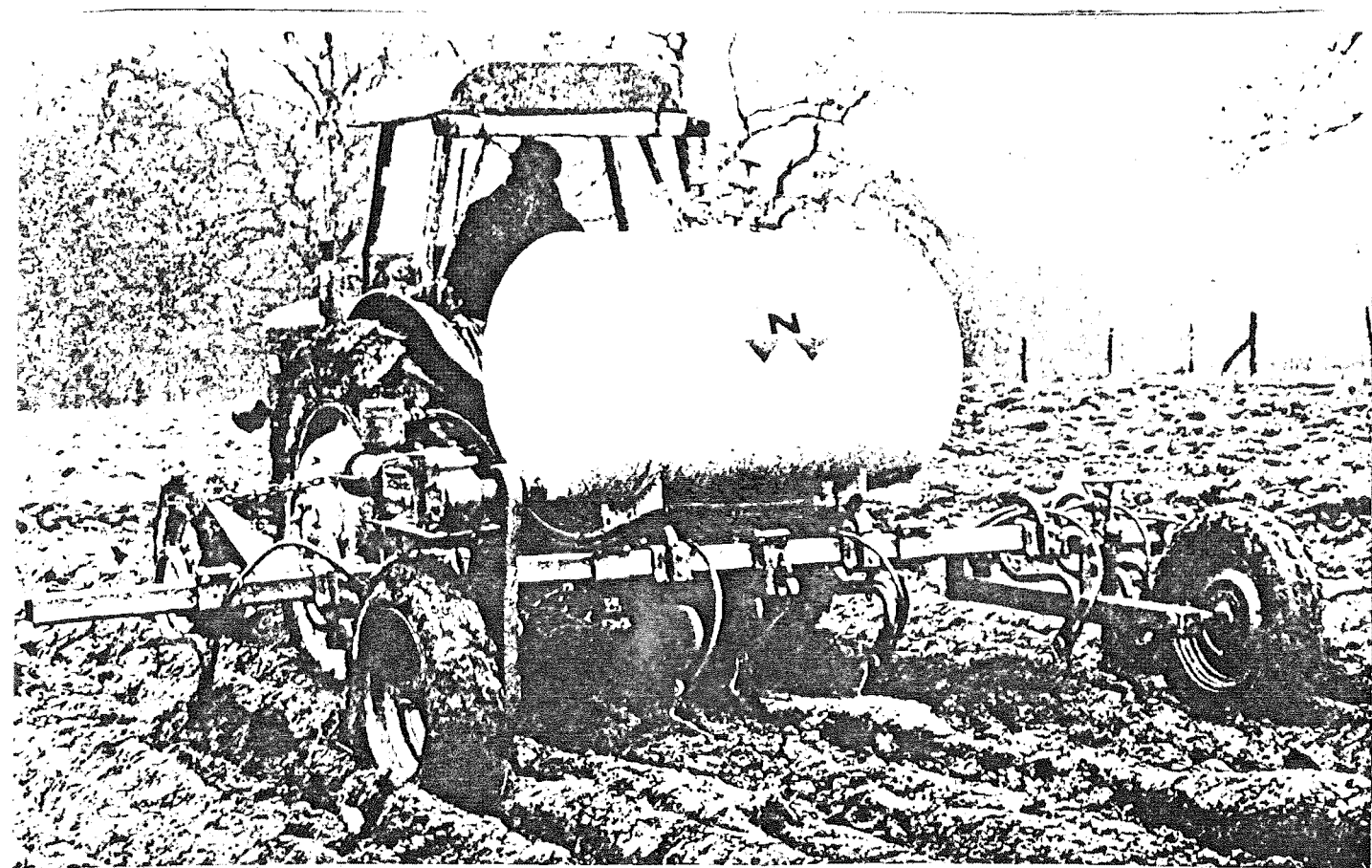
PLATE II

    Anhydrous ammonia applicator tank mounted on a cultivator
unit for application to ploughed land.

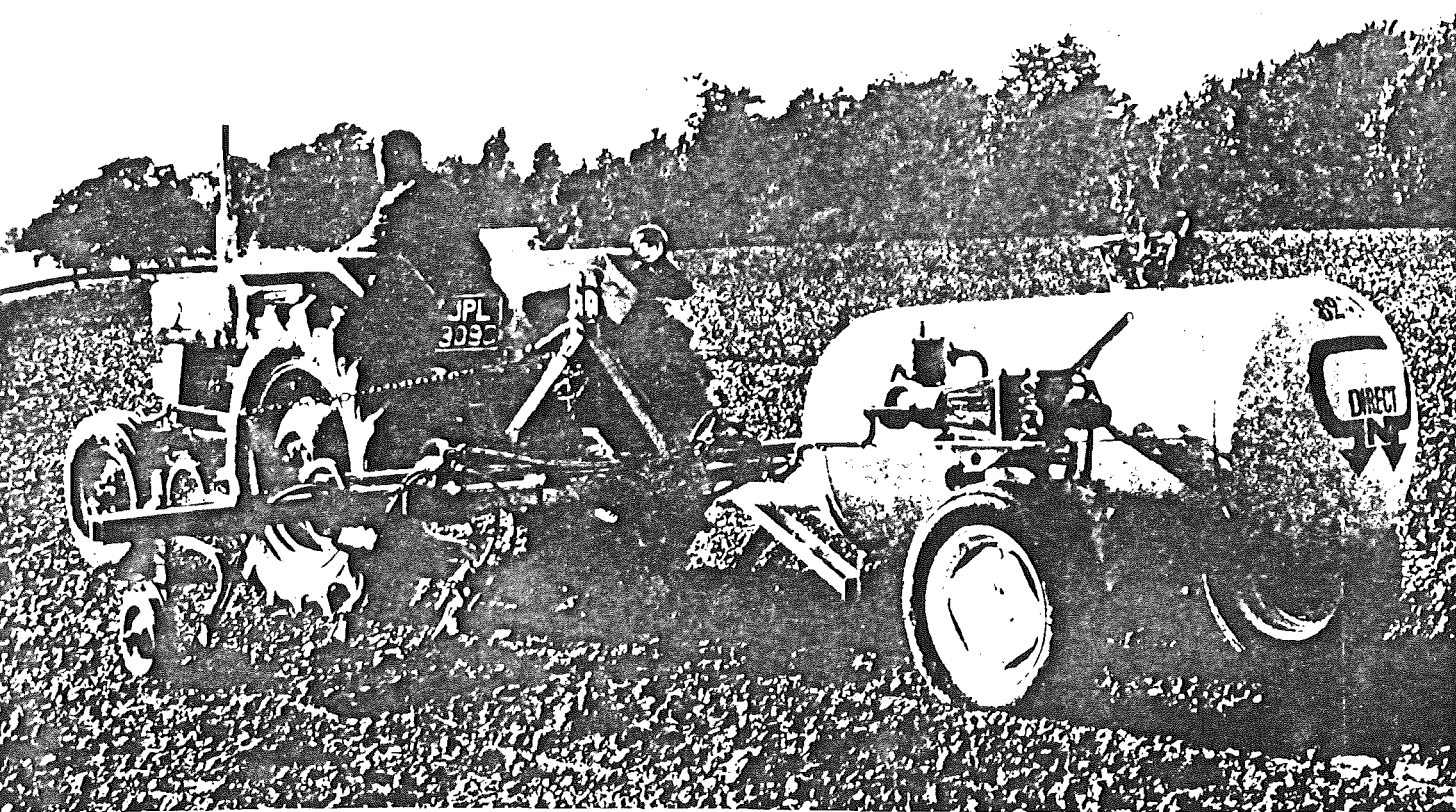   (Reprinted from Direct Nitrogen Limited).

PLATE III

A supply tank of Anhydrous Ammonia towed by a tiller unit.
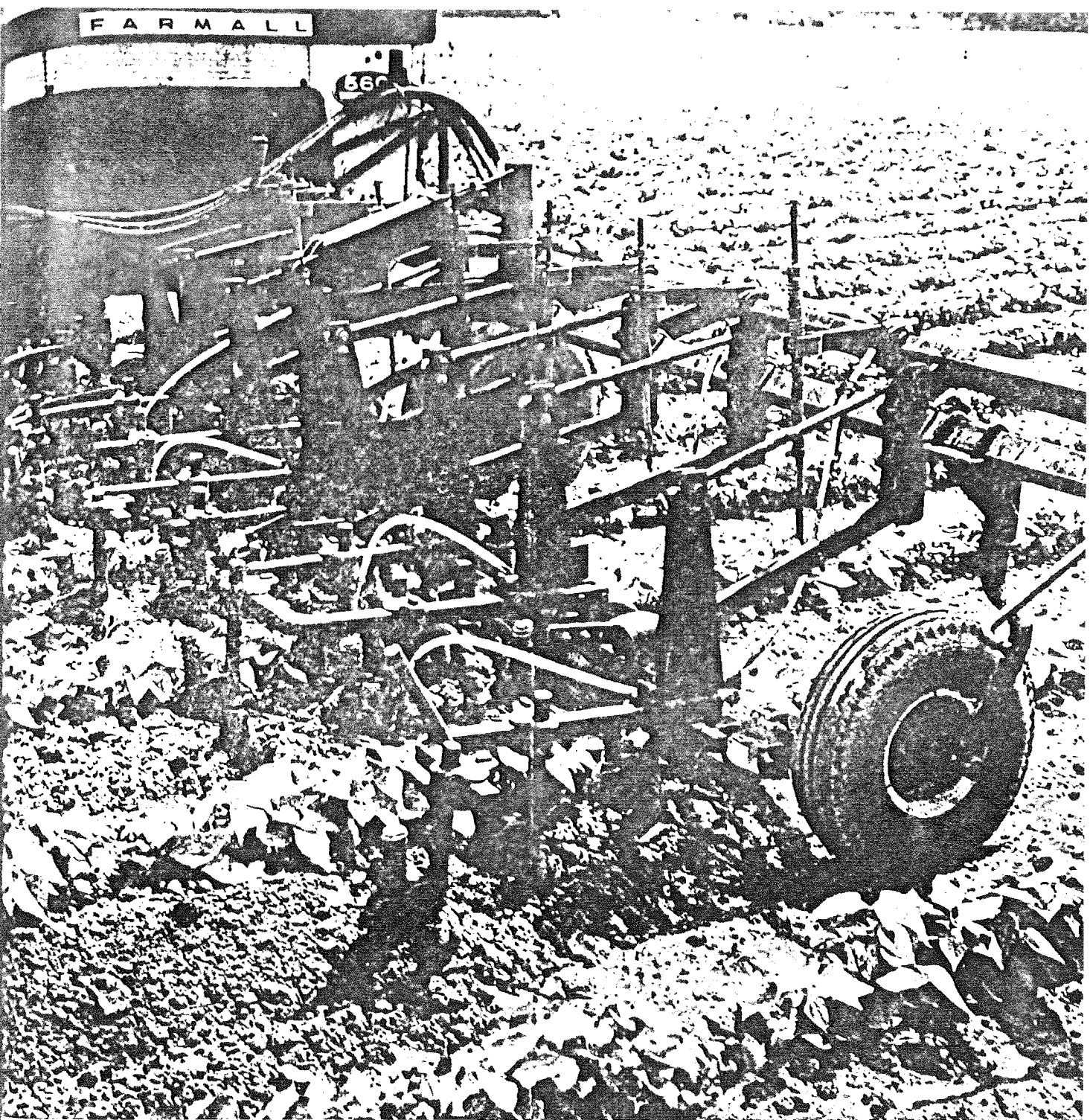(Reprinted from Direct Nitrogen Limited).

PLATE IV

Row Crop Application.
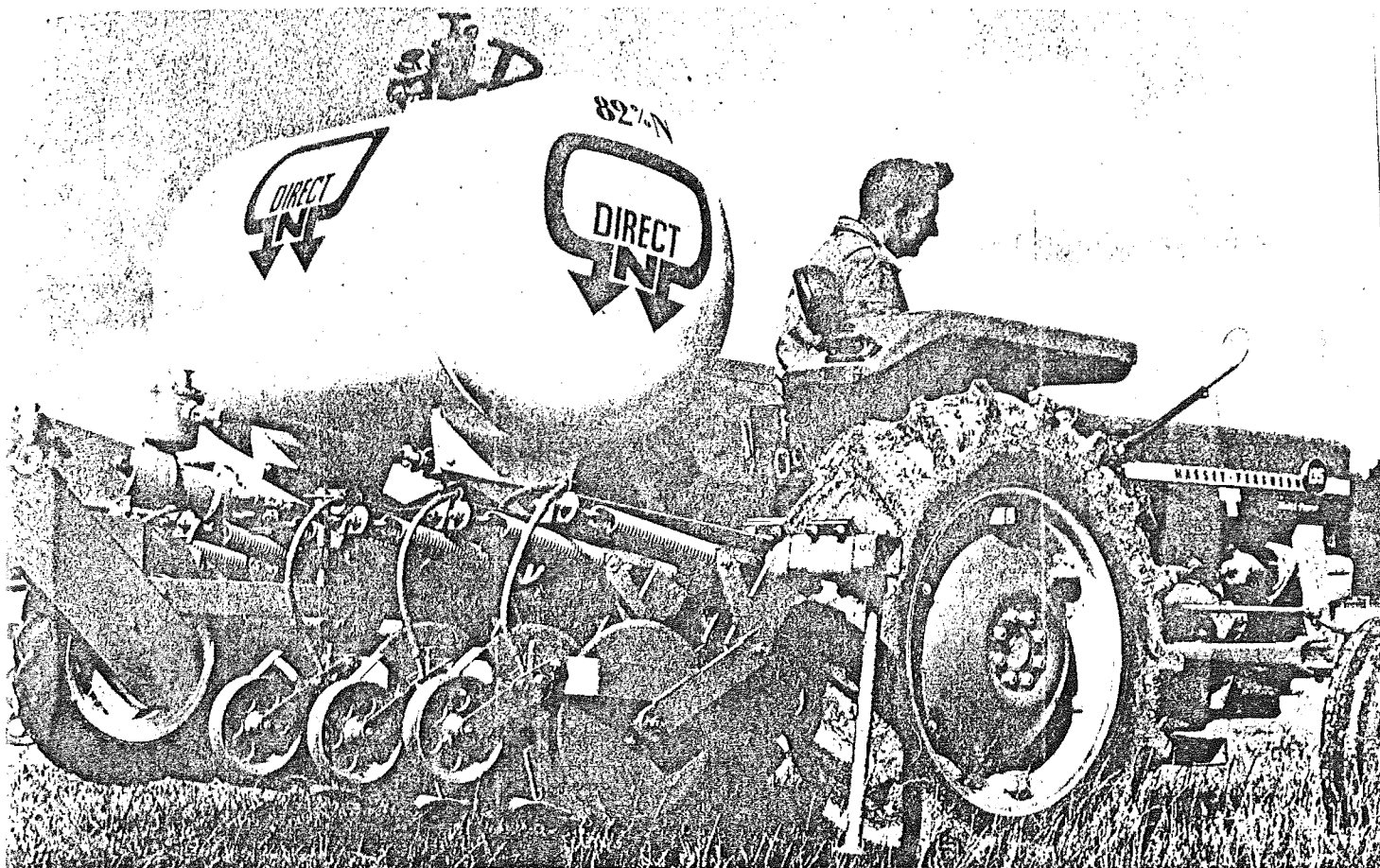(Reprinted from American Vegetable Grower) (Anon (6)).

PLATE V

A grassland anhydrous ammonia applicator.

(Reprinted from Direct Nitrogen Limited).

Thermometers may also be used on tanks where the density of ammonia needs to be computed.

Ammonia Flow Regulators

The next basic part of an ammonia applicator is the metering device. The accurate application of anhydrous ammonia requires it to be metered either as a liquid or a gas. However, mixtures of these two states will cause errors in measurement and application. In practice ammonia is measured as a liquid, and the devices currently used can be divided into to types:

1. Pressure

2. Pump

1. Pressure System

The amount of liquid delivered by the pressure system per linear foot of travel of the distributor is dependent on (Adams,1965):

(i) gauge pressure of the contained liquid.

(ii) orifice size

(iii) Static Line pressure.

(iv) speed of the applicator rig.

A uniform pressure and a constant speed of travel are necessary to maintain a uniform rate of application. Hedman and Turner (1954) studied the effect on application of various vapour to liquid mixtures and of adiabatic expansion from saturated to liquid ammonia. They correlated the density variations with changes in pressure with different initial pressures and stressed the

Safety Relief Valve

Vapor Bleeder Valve

Pressure Gage

Liquid Withdrawal Valve

Liquid Fill Valve

Fixed Liquid Level Gage

Liquid Level Float Gage
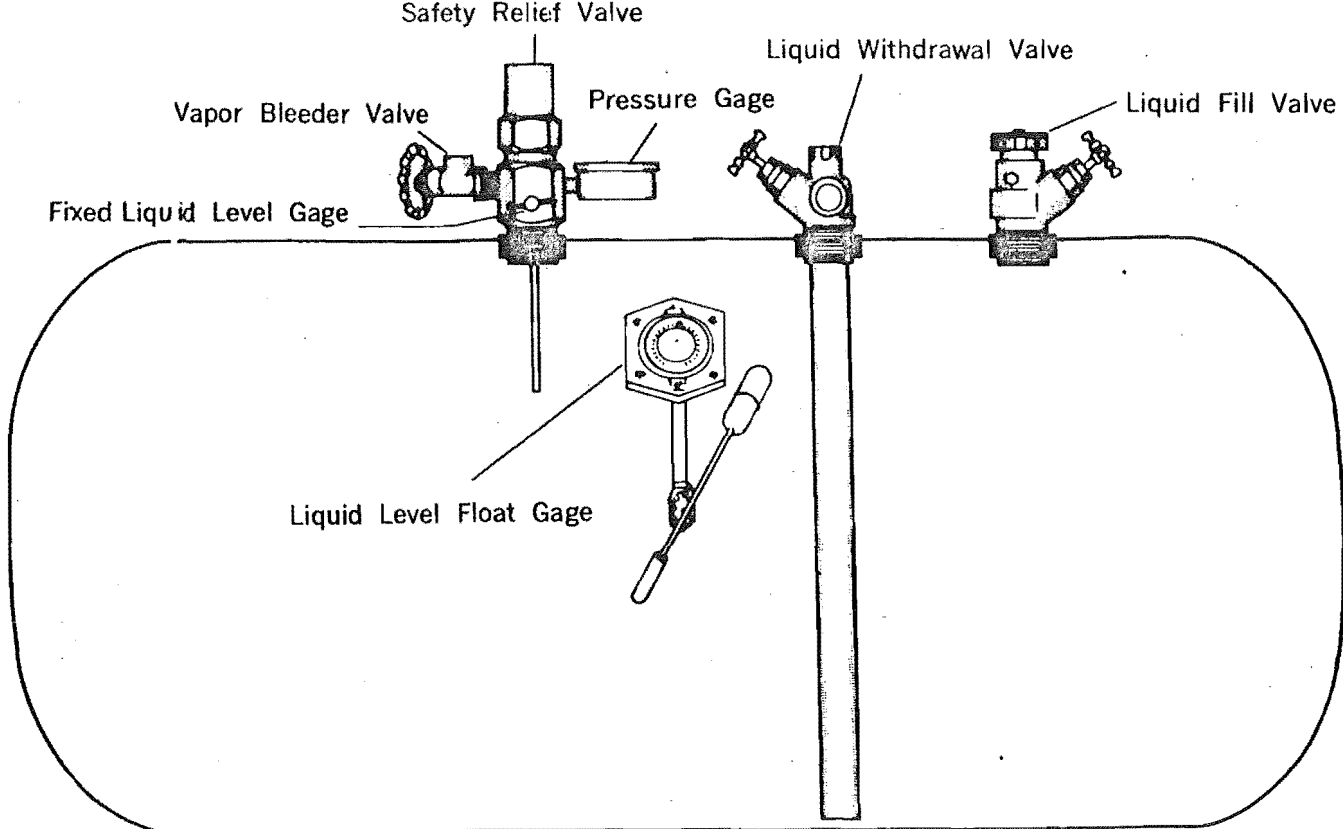
Figure VI.

4 - OPENING APPLICATOR TANK

Liquid Withdrawal Valve

Vapor Bleeder Valve

Safety Relief Valve

Fixed Liquid Level Gage

Liquid Fill Valve

Pressure Gage

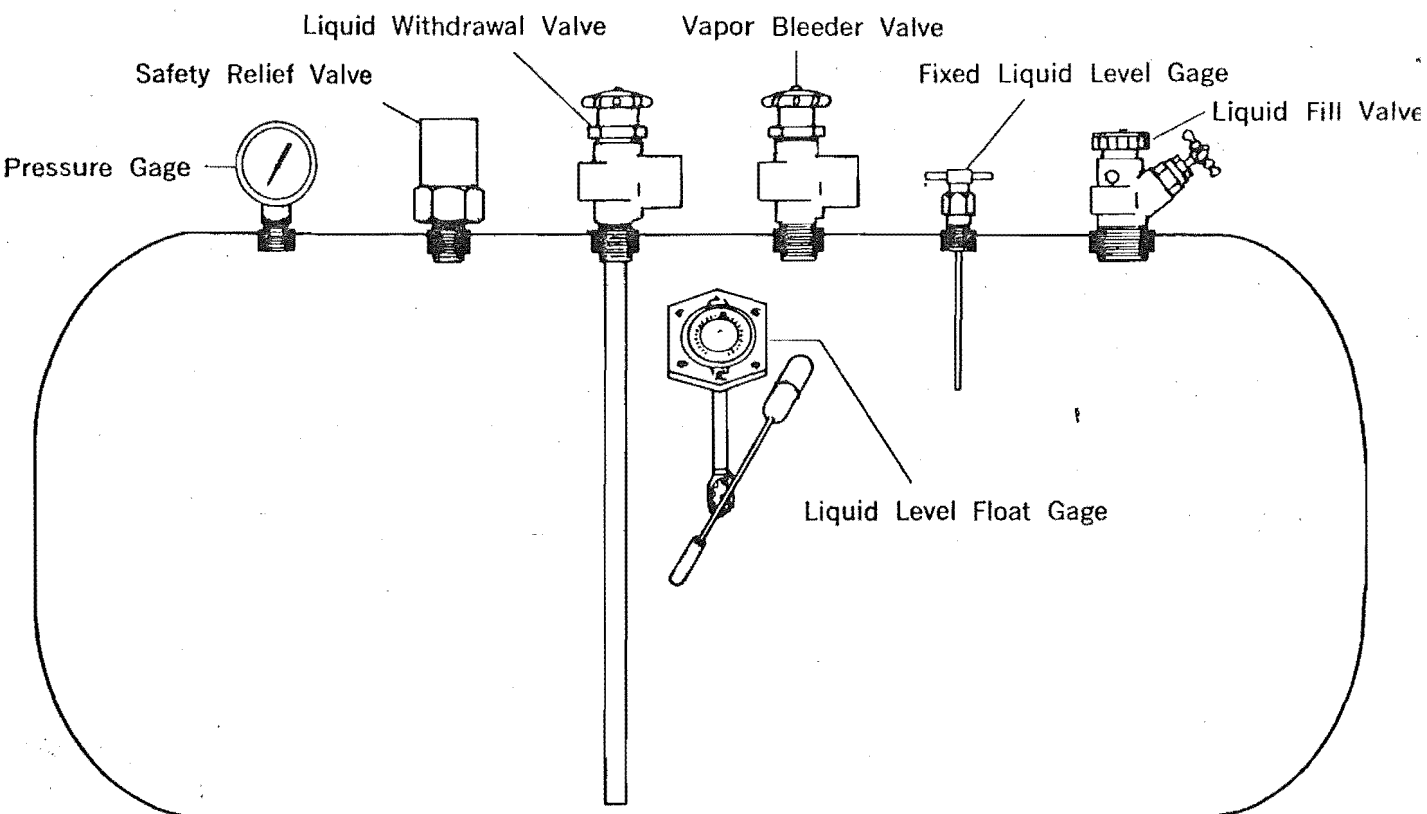Liquid Level Float Gage

Figure VII.

7 - OPENING APPLICATOR TANK

importance of maintaining a constant fluid density. They also came

to the conclusion that ammonia flow rate is principally controlled

by the following four factors - rate of application, tool bar width,

application speed, and ammonia pressure.

There are three types of pressure regulators:

(1) Orifice or needle valve.

(2) Adjustable pressure type.

(3) Variable orifice regulators.

(1) The orifice or needle-valve type are the simplest type

of regulating device but they do not compensate for changes in tank

pressures. Thus different sized orifices must be substituted, or

the needle valve adjusted, for each pressure change or when another

output rate is wanted.

(2) With the adjustable pressure types the pressure of the

ammonia within the regulator, against fixed output orifices,

determines the amount of ammonia injected. This type is more

accurate than the previous one.

(3) Variable orifice regulators depend on control by a

single built-in variable orifice. Settings are made on gauges

on the regulator bodies. This eliminates the need for calculations

which are required in other pressure regulating devices.

2. Pump System

Ammonia metering pumps are the most accurate means of

controlling application rate. This consists of a variable stroke

displacement pump and heat exchanger. The metering pump is driven from the rear axle of the tractor or from one of the wheels of a trailer applicator with length of stroke controlling amount of liquid entering the distributor manifold. This system must be equipped with a heat exchanger to prevent liquid vaporising and entering the metering cylinder. Length of the pump stroke is adjustable to raise or lower the output and the number of strokes per foot of travel can be varied using different drive-gear ratios. After a desired rate of application has been calibrated for a ground-driven displacement pump the rate per acre is fairly constant regardless of the speed of travel or variations due to uneven ground.

The principal disadvantages of this system are the relatively high initial cost and the expense of annual servicing which is an essential requirement of this type of equipment (Adams, 1965, Anon (a) 1965).

The principles governing application of anhydrous ammonia to soil are also applicable to aqua ammonia. Solutions are forced into the distributor manifold and through applicators by air compressors or solution pumps driven by a power takeoff or geared to the drive wheel of the tractor. A pressure regulating valve is required when using a compressor. This valve should be placed between the compressor and the solution tank to maintain a constant pressure in the solution tank regardless of the quantity of solution

and changes of temperature in the system but there is usually a
certain amount of pulsation irrespective of which pump is used.
A wide variety of pumps working on the tractor power take-off,
such as centrifugal, disphragm, gear, piston and roller are used.
Uniform application rates are difficult with these pumps as it is
necessary to have a constant ground speed.

DISTRIBUTOR MANIFOLD

The distributor manifold provides an equal amount of liquid/
gas mixture, to the individual tines. Hose nipples or combination
nipple-orifices are screwed into the outlet holes.

Injection Tines

These are the actual soil injection parts of the applicator
which resemble knife coulters on a plough. There are several
applicator knife designs from the conventional, thin evenly sloping
type, to backswept and chisel-faced modifications. They are
attached to a tool bar and cut into the soil to allow the applicator
tube to discharge ammonia at the required depth. The applicator tube
consists of a small metal pipe welded to the back of each tine and
through which the liquid/gas mixture passes. A sealing device
follows the tine and covers in the knife cut, thus reducing vaporisation
losses. There are many types of sealers, such as packer feet, rod
coverers and press wheels.

SURFACE APPLICATION

Both anhydrous and aqua ammonia can be used in irrigation water,
and in addition diluted solutions of aqua ammonia have been applied

with sprinklers to increase foliar absorption. However, care
must be taken to ensure that there is a low concentration to
avoid leaf burn.

Adams (1965) states that application of pressure liquids
in surface irrigation water needs careful design since on soils
with high infiltration rates an excessive quantity of nitrogen
may be found close to the water inlet. With anhydrous ammonia
it may also be necessary to add sodium hexametaphosphate to prevent
objectionable deposits of calcium carbonate on pipes and valves
when hard water is used.

Anhydrous ammonia is metered from cylinders under its own
pressure. Cylinders are laid horizontally on the ground adjacent
to head ditch or standpipe. The ammonia from a single cylinder
or in a manifold connecting two or three cylinders is measured into
the irrigation water through a hose connected to the metering orifice.
The rate of flow through the orifice is controlled by orifice size
and ammonia pressure which is regulated, in turn, by a control valve.

Application of aqua ammonia to surface irrigation water also
requires little equipment for the solution can be added using
gravity. Adams (1965) states that in the United States of America
tanks with extensible legs are carted to the site and set up in
their raised positions. A manually-operated control valve regulates
flow of aqua ammonia through a rubber hose into the irrigation water.
Atmospheric pressure is maintained in the tank by venting it to the

air and nitrogen losses through the aperture are negligible.
These mobile trailer tanks can be used for both anhydrous and
aqua ammonia.

LOSSES DURING SUB-SURFACE APPLICATION

Losses during sub-surface application are primarily due
to vaporisation although nitrogen salts in aqua ammonia exert no
vapour pressure and are not subject to loss. One of the first
essentials, particularly with sub-surface application, is to
have efficient leak-proof equipment while adequate sealing of
the knife cut made by the tines on an applicator rig is equally
important. It has already been stated in the previous chapter
that sub-surface application is most efficient when soil is in
good physical condition. For example, it would be hard to seal
ammonia in soil with a dry lumpy seedbed.

LOSSES DURING SURFACE APPLICATION

Surface application is subject to greater evaporation losses
than sub-surface application, particularly if the soil has a low
infiltration rate. Adams (1965) points out that a wide range
of nitrogen losses when ammonia is applied to irrigation water have
been recorded. He quotes workers who have estimated evaporation
losses as being negligibly small to one who quoted losses exceeding
26% under conditions of high water temperature and very low soil
permeability. Losses from irrigation water can be minimised by
irrigating in cool humid weather, maintaining a concentration not
over 110 ppm of ammonia, and keeping the exposed surface of flowing

water to a minimum by reducing the turbulence of the water and by using narrow but deep ditches (Adams, 1965).

Butler and Smith (1962) made a comprehensive study of ammonia losses using surface application from both tandom discs and mouldboard plough equipment. They reported that losses with a mouldboard plough were reduced to an acceptable level with a plough depth of 6 inches or more, a hose length of 3 feet running behind each plough body, and a lateral hose position of 4 to 8 inches from the furrow wall. Distribution was also found to be excellent for both types of machinery for rates up to 500 lb. of ammonia per acre. They stated that 90% of ammonia loss with both types of equipment occurred in the first 30 minutes and 97% within an hour of application, and that as a general rule on silt or silty clay if no ammonia could be seen rising then losses from tillage application should be less than 1%.

Storage

The pressure tank and its construction requirements was discussed when the applicator tank was described earlier in this chapter. In the United States of America anhydrous and aqua ammonia are required by farmers in spring and autumn. Ammonia plants, to keep running efficiently, produce ammonia all through the year and therefore storage is an important factor in usage of anhydrous and aqua ammonia.

Anhydrous ammonia is usually stored at the producer plant in

large spherical refrigerated tanks. These are called "Hortonospheres", have a capacity of several hundred thousand gallons and have moderately low working pressures. As ammonia vaporises within the sphere a compressor draws off the vapour, compresses it into a liquid and returns it to the sphere. Insulated spheres are used in some cases and ammonia is maintained at a temperature of -28°F. with a vapour pressure equivalent to 6 inches of water. Some producers store anhydrous ammonia in batteries of 30,000 gallon pressure tanks. Still others convert anhydrous ammonia to aqua ammonia and store it in low-pressure tanks. Plate VI shows a bulk dealer's plant where Hortonospheres, bulk tanks, and nurse tanks are visible, and Plate VII shows filling of an applicator tank from a nurse tank.

In United States of America storage of anhydrous and aqua ammonia at bulk distribution centres is usually by means of 15 - 30,000 gallon pressure tanks or in batteries of tanks with a 6,000 gallon capacity. The next smaller forms of storage are portable trailer or nurse tanks and farm storage tanks. Trailer tanks commonly have a 500 to 1,000 gallon capacity. Aqua ammonia can be stored in low pressure vertical tanks. Applicators can vary from 10 gallon to 750 gallon trailer rigs.

Transportation

Ammonia is transported by road, rail and water in the United States of America. A vast fleet of railway tankers carrying up to
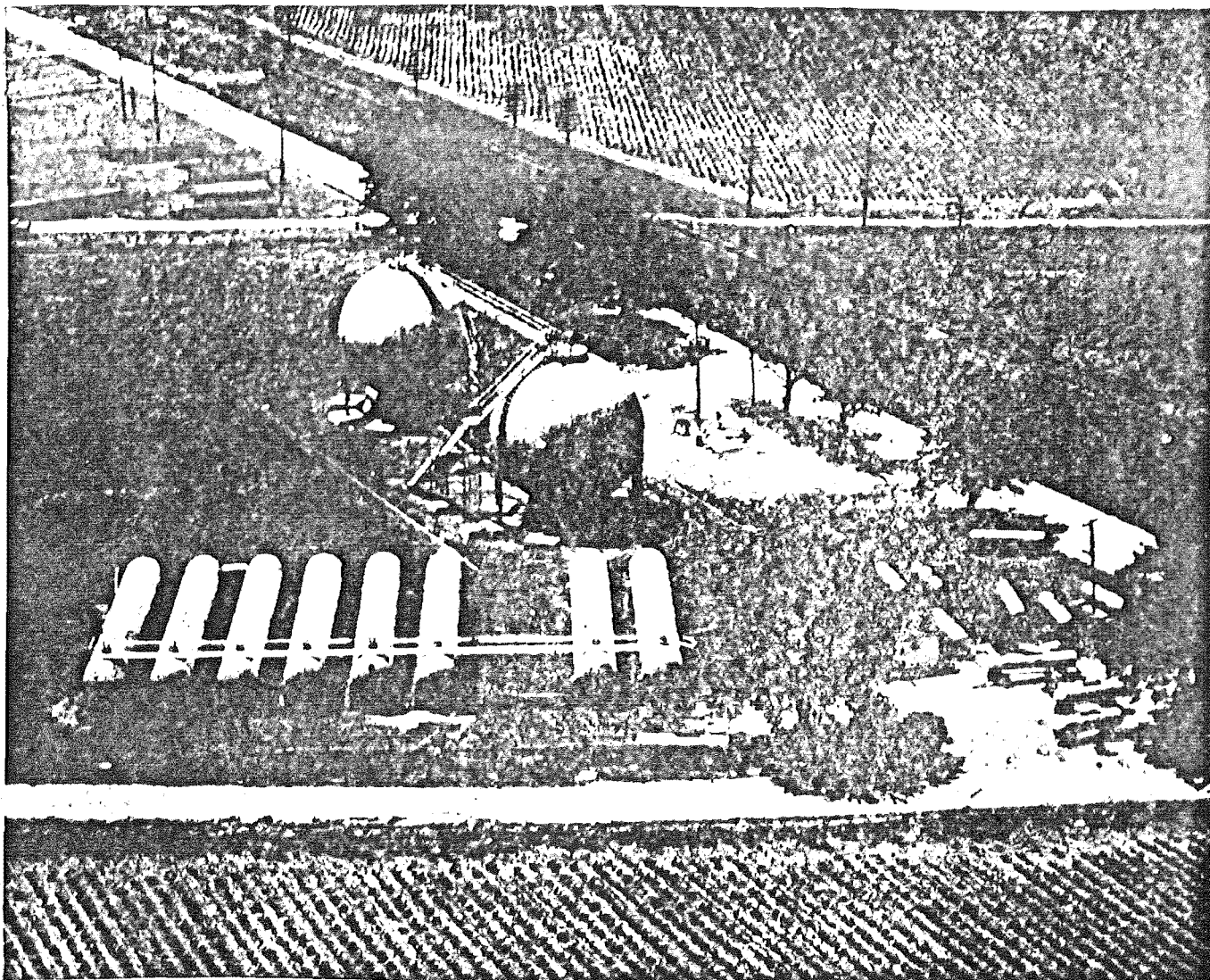
PLATE VI

Three types of Anhydrous Ammonia storage tanks are seen in this view of a bulk terminal. The 2 round tanks, centre, are Hortonospheres; the cylinders, left foreground, are 30,000 gallon pressure tanks; the trailer tanks, right foreground, are 1,000 gallon nurse tanks.

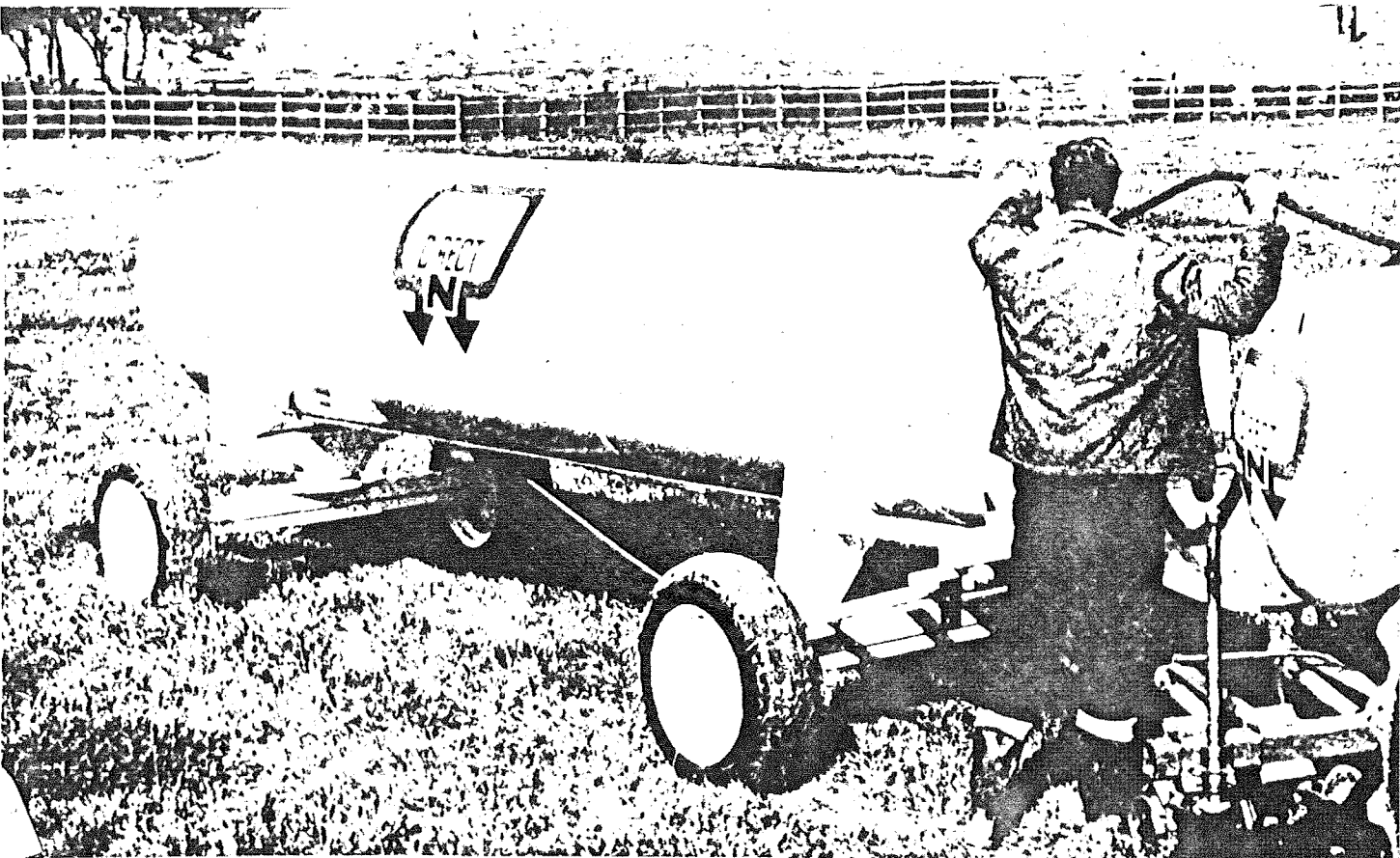(Reprinted from Anhydrous Ammonia Handbook) (Anon (1)).

PLATE VII

The nurse tank is used to transport ammonia from the storage tanks to the farm and, as shown above, is used as a refill source for the applicator feed tanks.

(Reprinted from Direct Nitrogen Limited).

10,000 gallons or 25 to 26 tons of ammonia under high pressure is used each year to transport anhydrous ammonia from producer to distributor. These tankers, referred to as "tank cars" are one of the major means of transport in the United States of America.

Sea transport is used by several producers in the United States. (Adams (1965) states that the first use of an ocean tanker was in 1953 when aqua ammonia was carried from California to Hawaii. Inland waterways are also utilised - making use of barges. This is a very economical method since one barge may carry 6 tanks with a total of 400,000 gallons of anhydrous ammonia.

Road transport from producer to distributor centre and thence to farmer is also of major importance in the United States of America and in Britain. Road transport is used for movement of large articulated trucks with capacities from 6,000 to 9,000 gallons in the United States, Britain and Australia.

Equipment for small scale Trial Work

There have been very few laboratory or glasshouse studies of anhydrous (or aqua) ammonia although it has become the leading source of N for direct application to soils in the United States of America (Parr and Papendick, 1966 (1)). However, in recent years apparatus for dispensing small quantities of anhydrous ammonia for laboratory and glasshouse work (Papendick and Parr, 1965), Papendick and Parr, 1966) and (Parr and Papendick, 1967) has been developed

at the Tennessee Valley Authority in the United States of America.
A British company has also developed a hand-operated device for
accurate placement of small quantities of liquefied ammonia
(Anon (10), 1968).   This hand-operated device consists of
a 4 lb. cylinder with a hose coupling connected to a hand-operated
lance or injecting probe.

CHAPTER 5

CROP RESPONSES TO AMMONIA FERTILISERS

EARLY USAGE AND HISTORY OF TRIAL WORK

More than a century ago Liebig suggested the possibility of
using ammoniacal liquors from coal gas plants as a source of
fertiliser nitrogen. Adams (1965) reports usage of ammonical
solutions on grassland in the 1840's - both in Scotland and in
England.   Anon (1) (1965) reports that early workers such as Maze
in France about 1898 and Prianischnikow, a Russian, about 1900, had
successfully experimented with ammonia as a fertiliser but their
work was overlooked. In 1908 the Haber-Bosch process for synthetic
ammonia production was first initiated and although it was soon
developed on a commercial scale, use of anhydrous ammonia as a
fertiliser was still a long way off, and increasing ammonia production
was largely utilised for military and industrial purposes.

J.O. Smith, of the Mississipi Delta Branch Experimental Station,
first used anhydrous ammonia by direct application in 1930 (Anon (1),
1965). Smith used a small ammonia cylinder on a plough pulled by
a mule. However, this work waited another fifteen years before general
commercial adoption.

Agricultural progress and the economic climate in the United
States of America was not ready for nitrogen fertilisation as a basic
farming practice, except in a few intensive cropping areas.

The most significant early step in the use of anhydrous ammonia in agriculture and horticulture came in 1932 when it was first applied in irrigation water (Anon (1), 1965). This work was extended to the point where water application of anhydrous ammonia was a substantial commercial business on the West Coast of the United States of America by the mid 1930's. Adams (1965) states that study of soil injection of anhydrous ammonia was begun in California shortly after application of this fertiliser in irrigation water had gained acceptance. Injection into soil proved feasible, and the first commercial application was made in California in 1939. Direct application of anhydrous ammonia was limited until supplies became plentiful after World War II.

LABORATORY WORK

In the United States of America Jackson and Chang (1947) carried out one of the first laboratory experiments. They used 800 ml. beakers, containing 1 kgm. of soil, to study the retention of anhydrous ammonia. Stanley and Smith (1956) described the use of stainless steel laboratory equipment to study the effect of soil moisture and depth of application of anhydrous ammonia. They reported that movement of ammonia within soil was least when the soil was of a good tilth. They also noted that there was a slight effect on availability of nutrients such as potassium, phosphorus and calcium. Sohn and Peech (1958) studying retention of anhydrous ammonia in glass bottles filled with soil found that in many cases

organic matter accounted for 50% of the ammonia retention.

Papendick and Parr (1965 and 1966) developed equipment for laboratory and glasshouse trial work at Tennessee Valley Authority in the United States of America. They followed this work up with a study of agronomic efficiency of ammonia using three glasshouse pot experiments in which they found that corn appeared to be remarkably resistant to high levels of anhydrous ammonia although some reduction of yield occurred due to root damage (Parr and Papendick (1) 1966). Their next studies involved an investigation into the effect of ammonia concentration and soil moisture on retention, which was discussed in Chapter 3, part 2 (Parr and Papendick (2), 1966). The distribution of ammonia, which was also discussed in Chapter 3, part 2, was examined in experiments at the Tennessee Valley Authority and related to agronomic efficiency of anhydrous ammonia (Parr and Papendick, 1967; Parr and Engibous, 1967). An interesting new development in the study of anhydrous ammonia has been the development of anhydrous ammonia-sulphur solutions. Parr and Papendick (3) (1966) described trials with corn in which these solutions compared favourably with other forms of sulphur fertiliser. Scott and Tisdale (1965) state that numerous compounds are quite soluble in anhydrous ammonia: the metal ammonium salts of copper and zinc, zinc nitrate, zinc oxide, elemental sulphur and elemental white phosphorus. They also state that while many more substances are soluble in ammonia it is

apparent from the examples given that the value of anhydrous ammonia

as a fertiliser may be increased if techniques for dissolving and

applying certain plant nutrients in this solvent can be developed.

PRACTICAL USES IN GRASSLAND AND CROPPING

Trials in America, notably in Mississipi, indicate that in

years with average rainfall ammonia is just as efficient a fertiliser

as ammonium nitrate; while in dry years ammonia is more effective.

However, work done in Denmark and England has shown that anhydrous

ammonia was inferior to materials like sulphate of ammonia (Van Burg

and Van Brakel, 1965), Cook, 1966), Jameson, 1959), and Hunter and

Jarvis (1953-54). It was found in Denmark that nitrolime gave much

higher yields and that the effectiveness was partly dependent on

having very thin tines (Van Burg et al. 1967). Jeater (1966), in

England, found that the action of aqua ammonia was very slow and that

the yields on pasture were 4 - 20% lower than those obtained from

equivalent amounts of solid fertiliser. Also in England, Webber

(1957) experimented with gas liquor which is a crude form of ammonia

liquid with 1 - 4% N. Gas liquor was sprayed on the surface and as

a result care was needed with applicators and weather conditions

to avoid scorching. Webber found that grass yields were 75% or

less of those obtained for sulphate of ammonia. Jameson (1959) and

Tod and Simpson (1956) also found, in England, that gas liquor

depressed yields by comparison with other nitrogen fertilisers.

Andrews (1956) reports that anhydrous ammonia compared very favourably

. with other sources of nitrogen in American trials.

Wheat, Oats and Barley

Andrews (1956) reported on a large number of preliminary
trials which were carried out in America. Although variable
results did emphasise the importance of applying fertiliser ammonia
at the right time and when soil microbes are able to carry out
nitrification on this ready source of ammonia. In general, the
use of anhydrous ammonia was fully as effective as ammonium nitrate
in promoting growth of these crops. Adams, et al. (1965) mentions
other workers who have found that anhydrous ammonia substantially
increased yields, and in other cases where it was equally effective.

In England Jameson (1959) found that winter wheat responded
equally well to anhydrous and also to aqua ammonia as it did to
other solid nitrogen fertilizers. Jeater (1966) also found, in England
similar results with spring barley but in the case of winter wheat
the results were not as good because it was considered ammonia was
applied too late.

Potatoes, Sugar Beet and Kale

The area of potatoes in New Zealand during the 1965-66 season
was 24,434 acres (Anon (7) N.Z. Yearbook, 1967). In trials in England
Jeater (1966) found that ammonia applied during potato planting gave
equal yields to soil nitrogen fertilizers but later application of
ammonia gave reduced yields by comparison. Andrews (1956) states
that in trials carried out in America in 1954 by Lorenze irrigation
of aqua ammonia gave much lower yields than the use of sulphate of

ammonia. Andrews also reports that anhydrous ammonia on potatoes compared favourably with calcium ammonium nitrate, and, in Denmark, was superior to sulphate of ammonia.

Van Burg (1967) reported on trials which he carried out in the Netherlands between 1936 and 1966. In the 1965 season much higher yields from potatoes and also sugar beet were obtained with anhydrous ammonia rather than conventional fertilizers. Further trials were carried out in 1966, on 3 soil types using these two crops, and it was found that injecting ammonia 1 - 3 weeks rather than 5 - 9 weeks before sowing or planting was much more satisfactory. Van Burg found that increasing nitrogen improved yields using conventional fertilisers but yields were depressed by increasing rates of anhydrous ammonia. Spacing of injectors was also examined by Van Burg. It was noted that very uneven stands of potatoes developed when the injectors were 90 cms apart, but at 60 cms the difference was not great, compared with control plots. Van Burg also reported on trials in which Oats, Spring Wheat, Potatoes and Sugar Beet were grown. It was found that anhydrous ammonia gave higher yields overall than conventional fertilisers. Autumn application of anhydrous ammonia was shown to be of value only when winters were cold as opposed to moist warm or mild winters when nitrification occurred and the fertiliser was consequently leached down into lower soil horizons.

Other workers in Denmark and England found in trials that anhydrous ammonia compared favourably with other nitrogenous

fertilizers for use with kale, sugar beet and potatoes (Mulder,1953. Hunter and Jarvis, 1953-54, and Jameson, 1959).

Maize

Maize is now quite an important crop in New Zealand, and in the 1965-66 season, 13,920 acres were grown (Anon (7) 1967. Eighty per cent of these crops are grown on the east coast of the North Island, and it is also gaining in importance in Northland (Dunne,1967). Maize requires about 160 lb. of nitrogen per 100 bushels of crop. This is higher than the potassium and phosphorus requirements which are 40 and 125 respectively (Graham, 1967).

In North Carolina nitrogen is considered to be the most limiting factor for producing corn. Corn yields can increase by about one bushel for each 2 lb. of nitrogen applied within the general ranges of response to nitrogen. It has been found in North Carolina that there were no differences in sources of nitrogen for corn when each was properly applied. However the residual or carry-over effect upon the acidity of the soil must be considered in long-term use of each fertiliser (Krantz and Chandler, 1954).

Other work by Chandler in North Carolina has shown that anhydrous ammonia and aqua ammonia are fully as effective as solid forms of nitrogen in promoting growth of corn. Andrews (1956) carried out large numbers of tests to compare anhydrous ammonia with materials like ammonium nitrate. For example, he found that when anhydrous ammonia was applied at 4 to 5 inches depth and ammonium nitrate was applied on the surface of the soil as early side dressing, the

increase of yield was 7 bushels for ammonium nitrate and 10 bushels for anhydrous ammonia. The inferiority of surface applied ammonium nitrate is attributed to lack of sufficient rain to leach it into the root zone. On average, anhydrous ammonia was slightly superior to ammonium nitrate for both pre-planting and side dressing. The thirteen tests carried out by Andrews on side-dressing also showed a slight superiority for anhydrous ammonia. The rate of application was 32 lb. of nitrogen per acre in these tests. Andrews also refers to a number of trials carried out in Delaware, Florida and Michigan and other areas in the United States where it has been shown that anhydrous ammonia is an equivalent or better fertiliser for corn than other conventional nitrogen materials.

Maize is a crop which is well suited to fertilisation with anhydrous ammonia since it has a high nitrogen requirement, a long growing season over the summer months and has wide row spacings. Since most maize crops are grown in a localised area in New Zealand it may be possible that there is a potential for contract application of anhydrous or aqua ammonia provided that an economic source of ammonia can be found. Large crops of sweet corn which are grown for processing could also be within the range of this technique. Maize growing in these East Coast, North Island, areas has already become quite highly mechanised.

Other Horticultural Crops

Andrews (1956) reports that anhydrous ammonia compared favourably with ammonium nitrate for french beans, cabbage, tomatoes

and sweet potatoes. He found that in order to avoid damage to
young plants a six-inch depth of application, and placement about
five inches to the side of the plants was preferable. Andrews
also refers to trials in Michigan where it was found that ammonium
nitrate was slightly superior to anhydrous ammonia for cabbage.
Though the differences were not large, the data suggested early
application of anhydrous ammonia to vegetable crops to ensure that
the nitrogen is in the form of nitrates early in the season. Other
work in Virginia showed also that it is important to apply anhydrous
ammonia earlier than, say, ammonium nitrate.

Lorenzo et al.(1955) carried out trials on a range of
vegetable crops shown in Table III:-

III Table: Response of crops to Nitrogenous Fertilisers
Yield assessed with Sulphate of Ammonia as a base level of 100.

Nitrogen Source	lbs. N per acre	Radish	Radish	Spinach	Peas	Cabbage	Lettuce	Onion
Anhydrous)	60	73	81	71	94	51	57	76
Ammonia)	120	89	87	96	81	91	51	86
Aqua)	60	91	93	87	101	88	80	71
Ammonia)	120	78	81	80	92	78	55	37
Sulphate of)	60	123	103	91	101	86	96	104
Ammonia)	120	100	100	100	100	100	100	100

These trials were carried out on a fine, sandy loam in which
risk of injury was quite high and indicate that damage can severely
reduce yields, particularly in sensitive crops like onions.

Lorenzo et al. made the observation that aqua ammonia is chiefly a gas in water and that the concentration of ammonia ions in solution at one time is very small. The ionization constant of ammonia is very small, 1.8×10^{-5} at room temperature, while sulphate of ammonia ionizes much more and the ammonium ions dominate.

They concluded that application of ammonia should be deeper and further from the plant than solid less concentrated fertilisers. However not all crops are equally injured and plants like sweet corn are much more tolerant to close placement.

J. Landy (1968) reports that although anhydrous ammonia has been largely used for wheat crops in New South Wales, Australia, a large amount has also been used in irrigation on cotton, sorghum, maize and horticultural crops. In Landy's opinion anhydrous ammonia is much more useful as a fertilizer under irrigation than when applied directly to soils because such areas allow for high application rates - thus cutting the unit cost of the fertiliser and irrigation, and also offering a stable outlet from year to year.

The use of anhydrous and aqua ammonia on vegetables in the United States of America is now common, particularly for those crops with a high nitrogen requirement (Balser, 1968; Anon (1) (1965). An examination of the importance of liquid nitrogen fertilisers was shown in a survey carried out amongst vegetable growers in the United States (Anon (6) 1966). The survey reported that usage of these materials was quite variable but in many

areas where dry fertilisers are used there is now a trend towards
liquid nitrogen fertilisers. Anhydrous and aqua ammonia is used
on a wide range of crops and this varied from State to State.
For example, in Pennsylvania liquid nitrogen fertilisers are of
particular importance on canning tomatoes, while in other areas
sweet corn, potatoes, green beans, peppers, snap beans and peas
are fertilised in this way. While the use of liquid nitrogen is
limited in some areas the survey showed that in California the
trend to increased use of nitrogen is occurring in all vegetable
cropping.

Finally, it was stated that the most significant trends in
the United States of America are towards bulk handling of fertilisers
and contract application.

The only crops in the United States which are not generally
given ammonia are the quick growing vegetables like lettuce when
planted in the winter since soil temperatures are so low that
nitrification is inhibited and nitrate is not made available fast
enough. Another of the rare exceptions is strawberries where,
with limited nitrogen use, there is little reason to use ammonia.
(Luckhardt, 1968).

Anhydrous ammonia has thus proved an excellent nitrogen
material for vegetables in the United States of America. For best
results proper depth and sidewise placement of the material is highly
important. Application in the desired position in the bed - either
by combination bedding and ammonia injection - side dressing, or

irrigation application is therefore highly desirable. Anhydrous ammonia is also an accepted fertiliser for all orchard crops in America. Direct soil injection in the middle of orchard rows, or application in irrigation water, is satisfactory for cultivated orchards. Where an orchard is kept in permanent sod and the roots grow just under the soil surface, direct injection of ammonia may be impossible without damage to roots. Work is being done in United States of America to develop applicators for these conditions (Anon (1) 1965).

Thus there is a trend towards greater use of ammonia fertilisers in the United States and overseas. This has become particularly apparent in certain areas in U.S.A where anhydrous ammonia is being used increasingly on vegetable crops. Trials indicate that horticultural crops will, in general, respond to anhydrous and aqua ammonia just as well as to other conventional nitrogenous fertilisers.

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CHAPTER 6

THE ECONOMICS OF AMMONIA USE

The main features that distinguish the economics of anhydrous
and aqua ammonia from other conventional solid nitrogen materials
is the distribution of costs.   The cost of producing anhydrous
ammonia is less than any other synthetic nitrogen fertiliser as it
is one of the raw materials required for manufacture of other
nitrogen fertilisers. Adams et al. (1964) in table IV below
demonstrate the competitive price of the two ammonia fertilisers
in the United States of America:

Table IV

F.O.B. Price of Chemical Nitrogen Fertilisers – 1964	Price per ton Us $	Price per pound N US cents
Anhydrous ammonia 82 per cent N	84.00	5.1
Aqueous ammonia 24.4 per cent NH_3	87.00	5.3
Ammonium nitrate 33.5 per cent N	70.00	10.4
Sulphate of ammonia 21 per cent N	32.00	7.6
Nitrogen solutions	1.69	8.5
Sodium nitrate	44.00	13.7
Urea 45 per cent N	83.00	9.2

Nelson,(1965), gives the following rough cost index of the
contained nitrogen in different carriers at producing plants in the
United States of America using 1963 prices:-

Anhydrous ammonia	1.0
Aqueous ammonia	1.03
Pressure type nitrogen solution	1.18
Non-pressure type nitrogen solution	1.48
Solid bagged fertiliser	1.87 – 2.46

Macadam and Noonan (1965) quoted 1964 prices for various nitrogen fertilisers in Australia:-

Fertiliser	Cost per ton Aust. £.	Per cent nitrogen	Cost per pound of N.
Sulphate of ammonia	29	20.5%	1/3
Calcium ammonium nitrate	39	20.5%	1/8⅓
Urea	52	46%	1/0
Anhydrous ammonia	–	82%	1/1

The cost of the individual nitrogenous fertilisers is far from being the only one to consider and the cost of the nitrogen applied to the soil rather than its f.o.b price is of prime importance to the farmer. It has been pointed out that the cost of anhydrous and aqua ammonia is quite low, however storage and handling, equipment and application costs are much higher. Since anhydrous ammonia is a liquified gas under pressure, operators must be experienced and follow all safety requirements. The cost of the nitrogen applied to the soil will therefore include the f.o.b price, freight, handling charges, cost of storage, a reasonable dealer mark up and cost of application.

Since the cost of anhydrous and aqua ammonia is low while the cost of getting ammonia from the producer and applying it is high, it will require to be applied on a certain minimum number of acres to become economic. The following figures demonstrate 1949 costs of applying 56 pounds of nitrogen per acre on 50 acres (Adams et al. 1965):-

Items of Cost	Anhydrous ammonia US$	Ammonium nitrate US$
Storage and handling	62.49	9.33
Application	71.27	44.08
Material	246.50	327.25
Total costs	380.26	380.66
Costs per acre	7.60	7.61
Costs per pound of nitrogen	0.136	0.136

These figures demonstrate that 56 pounds of nitrogen per acre in the United States of America, derived from anhydrous ammonia or ammonium nitrate, can be applied to 50 acres of cropland for 13.6 cents per pound. The importance of this is that if rates or acreage or a combination of these are increased, then anhydrous ammonia will become more economic. Under 1949 price relationships in the United States, 56 pounds of nitrogen per acre in the form of anhydrous ammonia could be applied to 850 acres for 10.2 cents per pound of nitrogen. The corresponding cost if ammonium nitrate was applied to 850 acres at the same rate, would be 12.9 cents, (Adams et al, 1964).

The cost of materials in each case constituted 86 per cent for anhydrous ammonia and 90 per cent for ammonium nitrate. The total cost for custom application of anhydrous ammonia at the rate of 100 pounds of nitrogen per acre was estimated at only slightly more ($10.30) than the purchase price of the equivalent nitrate (Adams et al. 1964).

Adams et al.(1964), also reported on a study which was carried out in Iowa, United States, to compare the cost of farmer-applied solid and liquid forms of nitrogen fertilisers. The study was based on fixed costs associated with the application equipment and storage facilities and such variable costs as the acreage fertilised, rate of fertilisation, cost of fertiliser, labour, and tractor power. Figure VIII illustrates the relationship between total cost per acre and acres fertilised at a rate of 50 pounds of nitrogen per acre.

Adams et al. drew the following conclusions from this work:-

1. A farmer with a 5-row applicator and a 550 gallon storage tank applied 50 pounds of nitrogen as ammonia per acre, on approximately 56 acres as economically as the same amount of a solid source of nitrogen was applied with a 12-foot distributor.

2. The cost of applied ammonia per acre was less than the cost of solid fertiliser when applied on more than 56 acres or when both were applied at higher rates.

3. The break-even acreage for a farmer without a storage tank was about 30 acres.

4. The break-even acreage for the farmer using non-pressure and low pressure solutions were approximately 185 acres if he had no storage tank, and 260 acres if he had a 550 gallon storage tank.

5. At a nitrogen application rate of 100 pounds per acre, anhydrous ammonia was applied for less per acre than solid nitrogen materials even on small acreages. This high application rate lowers the break-even acreages for non-pressure and low pressure solutions to 50 acres if the farmer has no tank and to 80 acres if a 550 gallon storage tank has been purchased.

6. Contract or custom application of anhydrous ammonia was 90 cents per acre less than for nitrogen solutions.

7. Nitrogen solutions can be custom applied on a small acreage at rates of 50 pounds of nitrogen per acre at a lower cost than the solid form can be applied with farmer owned equipment

8. At a rate of 100 pounds of nitrogen per acre, average contract costs per acre for anhydrous ammonia were less than the cost of farmer application up to about 120 acres. A comparable figure for the non-pressure and low pressure solutions was about 320 acres.

Luckhardt (1968) provided the following table which was compiled by farm advisors in California:-

Acres injected	Without Farmer Storage Either aqua or anhydrous ammonia	With Farmer Storage Aqua . ammonia	Anhydrous ammonia
	US $ per acre	US $ per acre	
300	2.80	3.50	6.30
500	2.30	2.70	4.30
700	2.10	2.40	3.60
1000	1.90	2.20	3.00
2000	1.80	1.90	2.30
3000	1.75	1.85	2.10

(100 lbs. N/acre, 45 days per year use of kit and nurse equipment)

The principal point that these figures illustrate is that the farmer must have a large acreage to economically justify owning storage equipment. Comparing contract application with farmer storage and using aqua ammonia, the extra costs of having his own equipment is 70 cents per acre when 300 acres are injected, but when 3000 acres are treated the difference is only 10 cents per acre. Similarly, comparing contract application and farmer storage, the corresponding differences fall from $3.50 to 35 cents for these acreages.

It can therefore be seen from overseas work on the economics of anhydrous and aqua ammonia usage, that rate of application, total
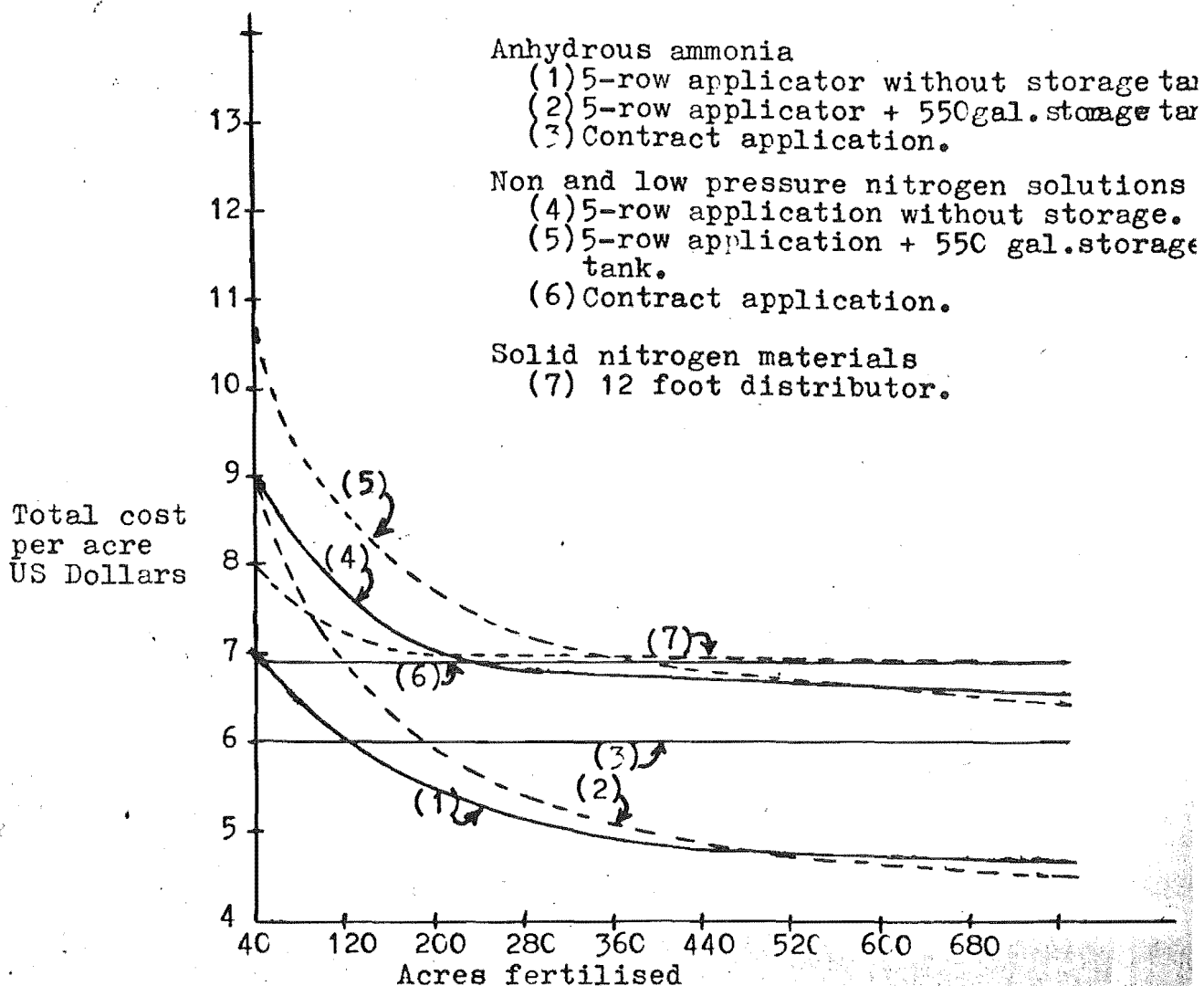
Figure VIII— Total cost per acre of applying 50 pounds of nitrogen in liquid and solid forms.

acreage to be fertilised, comparisons between contract application and farmer storage must all be taken into account when looking at application costs and the comparative price of conventional solid nitrogen materials.

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PART 3

ANHYDROUS AND AQUA AMMONIA IN NEW ZEALAND

CHAPTER 1

NITROGEN FERTILISER USAGE IN NEW ZEALAND

CROPPING PRACTICES IN NEW ZEALAND

The pastoral nature of New Zealand's agriculture is well known; there are $19\frac{3}{4}$ million acres of sown grassland plus 12 million acres of tussock grassland.   On the other hand there were in 1965-66 2,701,141 acres of arable crops grown (Anon (7) 1967). This gives a pasture to arable ratio of about 11.5 : 1.   In the United States of America, there were 1,120,158,000 acres occupied by farms of which 313,446,000 acres were cropped in 1959. Assuming that most of the non-cropped land is pasture then the pasture to arable ratio in the United States of America is about 2.7 : 1. The main point arising from these figures is that the pastoral to arable ratio in New Zealand is very much higher than it is in the United States of America.

The total area of crops in New Zealand has increased from 2,378,997 acres in 1961-62, to 2,701,141 acres in 1965-67 (Anon (7) 1967). This indicates that cropping is at least keeping its significance and may possibly be on the increase. Vegetable growing accounts for 2 - 3% of the total cropping land with 40% of holdings under 10 acres. This is in direct contrast to America where emphasis is on specialisation on large areas with few crops.

The trend towards extensive crop production has become apparent in New Zealand over the last few years particularly with crops where mechanisation is possible, such as potatoes, peas, beans, sweet corn, tomatoes, carrots, cabbages and onions. There has also been a trend to crops with higher gross margins, and farmers in particular have looked to crops like onions for higher net returns. It is under this system of growing, using large acreages but few crops, that anhydrous and aqua ammonia could play an important part, helped perhaps by contract application.

One particular aspect of specialised vegetable growing is the production of process vegetable crops. The acreage of these crops has increased from 16,357 acres in 1961-62, to 18,287 acres in 1965-66 (Anon (7) 1967). The consumption of processed vegetables in New Zealand is one of the highest in the world at 26 lb. per head compared with United States of America at 11 lb. per head. Thus the growing of process vegetables is an important and enlarging aspect of vegetable cropping, and along with specialised growing of fresh vegetables lends itself to contract application of anhydrous and aqua ammonia. There is a trend to diversify away from traditional cropping and many new crops like sunflowers, rice and soya beans are being tried. The first commercial crop of sorghum was grown in Gisborne this season and this has a similar nitrogen requirement to maize. The potential of large areas like the Canterbury Plains has hardly been exploited for intensive cropping.

Comparative Usage of Nitrogen Fertilisers

Anon (8) (1967) gives the following figures for ·fertiliser

usage in New Zealand (in thousands of tons):-

	1958-59	1965-66	% Increase
Sulphate of ammonia	10.0	15.9	59
Nitrate of Soda	0.4	· 3.7	82
Organic fertilisers	32.2	37.3	15.8
Total phosphates	878.5	1656.8	88.7
Total potashes	55.6	150.4	169.5
Total of all fertilisers (N P & K)	976.7	1864.1	90.4

The table above indicates that nitrogenous fertilisers are

only a very small portion of the total fertilisers used, and, in

fact, they have fallen in seven years from around 4% to 3%. There

has been a marked stress on use of phosphatic fertilisers in New

Zealand such that importance of nitrogenous fertilisers and their

potential value in many instahces has not been given the attention

it deserves. Legumes are used almost exclusively for the building

up of nitrogen in pasture and phosphatic and potash fertilisers

dominate the increased use of fertilisers over this period. Nitrogen

fertilisers, of which organic materials predominate, have only

played a small part in the increased usage.

The use of nitrogenous fertilisers in horticultural crops is

well established and there is a wide range of materials available.

It is noticeable that organic fertilisers account for the largest part of nitrogen fertilisers used in New Zealand. This was 65.6% of the nitrogen fertiliser used in 1965-66 and although home gardens must account for quite a large amount, these high-cost low-analysis nitrogenous materials clearly do not justify their dominant role, as will be shown in the next chapter.

Nitrogenous fertilisers used in horticulture vary from materials containing only nitrogen to those that contain phosphorus, potassium and minor elements combined with nitrogen. The most commonly used artificial nitrogenous fertiliser is sulphate of ammonia (four times the tonnage of any other), even though it has a strong acid reaction in soil and the fact that it contains only 21 per cent nitrogen. Organic materials like blood and bone, and bone flour contain less than 10 per cent nitrogen but usually contain phosphorus in addition. There are small amounts of ammonium nitrate and calcium nitrate used in New Zealand, and an even smaller but growing tonnage of urea. This differs from the overseas trend of much greater use of high nitrogen analysis fertilisers. The economic aspects of this will be discussed in the next chapter. Combined fertilisers have become popular in New Zealand and examples of these are Nitrophoska, Ammophos and Rustica. The range of nitrogen in these mixtures, however, is not great since none of them contain more than 20 per cent nitrogen.

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CHAPTER 2

ECONOMICS OF NITROGEN FERTILISERS IN NEW ZEALAND

Having examined the current use of nitrogenous fertilisers and their relationship to cropping practices in New Zealand, the economic aspects should be looked at next. The source of nitrogen fertilisers for New Zealand, and the comparative costs with anhydrous and aqua ammonia is of prime importance in this study.

Imports of Nitrogen Fertilisers

Most of the artificial nitrogen fertilisers used in New Zealand are imported. The total nitrogenous fertilisers imported into this country for the year ending 1960 amounted to 16,676 tons (Anon (8) 1967). This has since risen to 25,168 tons for 1965-66. The following figures were obtained from the Statistics Department, (Anon (9) 1968) for the year ending June, 1967:-

Fertiliser	Tons	Current Domestic Value	Principal Suppliers	
Ammonium nitrate	996	48,772	West Germany	55%
			United Kingdom	25%
Ammonium Sulphate	12,738	416,666	West Germany	35%
			Japan	30%
			Netherlands	20%
Calcium nitrate	1,853	45,804	Belgium & Lux.	44%
			West Germany	50%
Calcium Cyanamide	5	214	Japan	100%
Natural Sodium Nitrate	2,600	91,402	Chile	98%
Urea	1,289	88,628	West Germany	41%
				24%
Other kinds of N Fertiliser	7,279	310,228	West Germany	39%
			U.S.A	18%
			Belgium & Lux.	16%
Total:	26,760	$1,001,716		

The total current domestic value for all types of fertilisers including phosphatic and potash fertilisers imported into New Zealand for this period was $4,861,460. By comparing this figure with the total imports of nitrogenous fertilisers it can be seen that the latter account for nearly 25 per cent of the total value of fertiliser imports.

Fertiliser Costs

Farming in many countries which were initially pastoral has been encouraged to diversify into mixed cropping by the use of subsidies on fertilisers.

Nitrogen fertilisers are not subsidised in New Zealand while in countries like Britain and Australia costs of these materials are effectively lowered by this method. Anon (6) (1967) gives the following subsidies for England:-

Fertiliser	% N	Subsidy per ton
Nitrate of Soda	16	£4. 14. 8
Sulphate of Ammonia	21	6. 4. 3
Nitro chalk	21	6. 4. 3
Nitra shell	26	7. 13. 10
Bone Meal	4	none
Hoof and Horn	13	none

Pickering (1967) states that five years ago Australians were using one unit of nitrogen to 15 units of phosphate. Today they are using one to ten. He also reports that the Australian Government since late in 1966 has paid a bounty of $80. a ton for nitrogenous fertilisers and this was undoubtedly another reason for the increased usage in Australia. Five years ago the only nitrogen used in Australia was on horticultural crops but now it is used on wheat, cotton, sugar cane, rice, grain, sorghum and winter pastures. Pickering (1967) reports that imports of urea into Australia rose from 9111 tons in 1958-59 to 47,810 tons in 1963-64 and that there is a positive upsurge in the use of nitrogenous fertiliser in that country. This does not appear to have occurred in New Zealand and this may be accounted for by several reasons;

the lack of subsidies, a smaller proportion of arable farming, and the lack of fierce competition, promotion and advertising amongst fertiliser companies.

Wild (1960) states that New Zealand soils are as a rule richer in nitrogen than are those of England; the average content of soils of the chief arable districts in New Zealand is 0.25% as compared with 0.15%, which is the average of some typical fertile soils in England. This is accounted for by the milder conditions in New Zealand which allow faster nitrification under similar moisture regimes. Probably the most significant factor in the low use of nitrogenous fertilisers in New Zealand is the overall pastoral nature of the agriculture in this country and the traditional method of allowing legumes to supply nitrogen to pastures. Nitrogen must be used carefully and in no way can it be considered in the same light as phosphatic fertilisers. Pickering (1967) summarises the position in Australia by saying that nitrogen there is on the increase subject to the three limiting factors of management, moisture and finance.

Evaluation and Cost Comparison of Nitrogen Fertilisers

When examining the costs of fertilisers it is important to compare them on a 'Unit Basis'. In this case the cost per lb of nitrogen is used as a standard for comparison. The cost per lb. of nitrogen allows an evaluation on the basis of active ingredient and is made up from the following:-

Cost per lb. of nitrogen = $\dfrac{\text{Price ex Store per ton}}{\text{lb. of N per ton} \times 2240 \text{ lb/ton}} \times \dfrac{100}{1}$

Fertiliser	% N-P-K	Price to farmer (ex store) (bagged)	Price per lb. N
1. Sulphate of ammonia	21-0-0	$55.70	12 c.
2. Urea	46-0-0	$100.70	10 c.
3. Blood and Bone	7-7-0	$64.	41 c.
4. Nitro Lime	21-0-0	$64.25	13.7 c.
5. Nitrate of soda	16-0-0	$65.50	18 c.
6. Anhydrous Ammonia			
(1) Ex gas works in N.Z. 25 lb. cylinder	82-0-0	–	25 c.
(2) Imported price to buy from Australia in 95 lb. cylinder	82-0-0	–	20 c.
(3) Commercial or ex store price in New Zealand	82-0-0	–	34 c.
(4) Price in Australia	82-0-0	$184.41/ton	10 c

This costing applies to a farm situated up to and including 20 miles from the static tank. Thereafter the price increases at the rate of 15 cents/ton/mile.

Application costs of anhydrous ammonia in Australia (Landy, 1968) are as follows:-

Broadacres	–	$1 per acre
Row crops	–	$2 " "
Rice	–	$1.40 per acre

The price per lb. of nitrogen for various fertilisers gives only an approximate indication of the various unit prices. Perhaps the most important feature of these prices is that blood and bone has much the highest price per lb. of nitrogen although this can be partially offset by the phosphorus content. As stated in the previous chapter, organic fertilisers accounted for 65.6% of the total use of nitrogen fertilisers in New Zealand in the 1965-66 season, yet it can be seen from the figures for blood and bone that organic materials have a very high cost per lb. of nitrogen. It appears, therefore, that greater use of fertilisers with a lower cost per lb. of nitrogen would be worthwile. This is probably an important factor accounting for the trend towards more concentrated nitrogen fertilisers, with a low cost per lb. of nitrogen, in countries like the United States of America. It can be seen from the table of fertiliser prices that the cost per lb. of nitrogen in blood and bone, which is the principal nitrogen fertiliser being used, is even greater than that for anhydrous ammonia imported in 95 lb. cylinders from Australia.

A significant feature of imports of nitrogen fertilisers into New Zealand is the large tonnage of sulphate of ammonia imported. Yet this material contains only 21% nitrogen and is therefore costly to import per lb. of nitrogen. It is also noticeable that sulphate of ammonia comes principally from Europe and Japan. This is in direct contrast to urea which is a high analysis material (46% N) but only a small tonnage is imported each year from Japan.

Anhydrous ammonia on the other hand is an 82% nitrogenous material which could come directly from Australia but bulk or refrigerated tanks would be needed for shipment of large quantities. A feature of anhydrous ammonia is that once large enough quantities are being used then the very low cost per lb. of nitrogen will offset the cost of specialised shipment, storage andapplication. In this way anhydrous ammonia has become the most economical nitrogen fertiliser in America.

The price of anhydrous ammonia even if imported from Australia is clearly competitive with that of other nitrogen fertilisers. The position is even stronger in Australia where prices of solid fertilisers are comparatively greater. For example sulphate of ammonia, in Australia is 11.1 cents per lb. of nitrogen ex factory, not ex store (Landy, 1968).

The case for manufacture of anhydrous ammonia in this country needs urgent examination if New Zealand is to venture into extensive crop production.

PART   4

CONCLUSIONS

CONCLUSIONS

The need for nitrogen has been established as an essential but variable major element for the growth of plants. Nitrogen can be absorbed in the ammonium form in preference to nitrate and has the advantage of being strongly held on soil colloids against leaching until conditions are suitable for growth. Thus anhydrous and aqua ammonia can be applied in autumn for spring crops. In addition these liquid fertilisers have been shown to have a potential for carrying other nutrients like sulphur and may have scope as herbicide and therapeutant carriers.

As the use of nitrogenous fertilisers increases the economics of methods of nitrogen application become more important. Overseas it has been shown that nitrogen from anhydrous ammonia per unit of N. is by far the most economic means of supplying nitrogen to the plant if areas or rates are sufficiently great. Consequently a great increase in the use of this material has occurred in all fields of agriculture and horticulture with much success. Anhydrous and aqua ammonia are however virtually unknown and untested in New Zealand.

In New Zealand fertiliser use has largely involved only phosphorus and potassium applications, while nitrogen has been supplied through N. fixation in clover nodules. As a result nitrogen fertilisers are largely organic sources or relatively low analysis inorganic forms such as sulphate of ammonia.

If New Zealand is to maintain its position as an agricultural nation and diversify into a wider range of primary products it must develop the most favourable economic climate for export. Increased yields and lower costs of production must take their part in this, and greater and more efficient use of nitrogen has been shown to be an important part of this development.

In New Zealand there must be a strong trend away from the expensive organic sources of nitrogen to more economic sources of inorganic nitrogen. The production of cheaper electricity from hydro-electric power schemes has increased the feasibility of an ammonia plant in this country. However if this development is not currently possible then only nitrogen fertilisers of the highest concentration should be imported and then from the closest sources. Such fertilisers are not sulphate of ammonia at 21%N or Urea at 46% but the highly concentrated forms of anhydrous ammonia at 82%N.

There is no doubt that both agronomically and economically anhydrous and possibly aqua ammonia offer very great possibilities for New Zealand agriculture and horticulture. The next step is to demonstrate these advantages effectively under New Zealand conditions.

ACKNOWLEDGMENTS

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