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Importance of Legumes, Especially The Trifolium Species, in Range Improvement

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IMPORTANCE OF LEGUMES, ESPECIALLY THE TRIFOLIUM SPECIES, IN RANGE IMPROVEMENT

by

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Species, in Range Improvement

by

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This paper analyzes the most important characteristics of legumes, which have led to their utilization in range improvement all over the world. It emphasizes the *Trifolium* spp. (esteemed among the legume family), their contributions to soil and forage improvement, and the success obtained from their utilization, especially in semi-arid ranges. Many references originally from Australia, United States, Morocco, and Portugal were used as sources of data because of the ample utilization of these species in these countries. Careful analysis related to requirements, potentialities, and production of clovers were used and recommendations were made for different ecological areas where establishment could be a success.

(149 pages)

INTRODUCTION

Today's world population explosion has generated a massive hunger problem. There is a great shortage of protein calories, vitamins and minerals. Our soil fertility, particularly in terms of nitrogen availability, is decreasing progressively by land misuse, improper management and erosion. Artificial nitrogen fertilizers have become more and more expensive and even unavailable in many countries. Legumes appear to be the most appropriate means to solve a major part of these problems. Their esteemed position is due particularly to their ability to fix considerable quantities of atmospheric nitrogen when they have developed a highly specialized association with specific bacteria. The symbiotic nitrogen fixation process is a unique, beneficial, and inexpensive phenomenon.

The high value of legumes as an important source of human food, animal forage, and soil improvers has been recognized since the beginning of agriculture (Kjar, 1960). Legumes featured in the cropping system of the early Egyptian dynasties, and later in the Roman era several writers stressed their value for food and soil improvement (Whyte, Leissner and Trumble, 1953). Alfalfa can be considered as the earliest cultivated forage crop and soybean as the earliest food crop (Wheeler, 1950). Likewise, the native small clovers, trefoils and vetches have been common, and highly regarded in meadow land; it is from these that most sown pasture legumes have arisen (Bartholomew and Clark, 1965).

Although there was an early recognition of the importance of legumes, man used them a long time before he knew what made them useful, where they could be cultivated, and how they should be manipulated in order to attain the maximum profit in terms of range improvement and livestock production. Most of their biology remained unknown until revealed by some recent and eminent scientific investigations that led to new ideas about nitrogen fixation by legumes and symbiotic bacteria and its practical applications. These concepts, as well as the important position of legume species as livestock feed, in soil conservation and soil improvement, will be discussed in the first part of this paper.

Throughout the world, there are nearly 500-600 genera that can fix N, and some 11,000 species of legumes (Heath, Metcalfe and Barnes, 1973). Many scientific investigations have been performed in order to select the most important and appropriate species and ecotypes in terms of adaptation, production, resistance and economic constraints. From these selected legumes, the Trifolium spp. or "true clovers" are among the most recommended for forage and range improvement because of their production potentialities, their broad tolerances and adaptations, and their nutritional values. Their wide utilization is well known in most ranges around the world, particularly in Australia and around the Mediterranean where in semi-arid areas they rank first among the legumes in importance. The high value of the Trifolium spp. in range improvement will be the second topic of this thesis.

GENERAL ROLE OF LEGUMES IN PASTURES

The word legume is derived from the Latin _legere_, to gather, presumably because it was the custom to collect the seed pods of legumes by hand, rather than by a sickle, as with grasses, which do not shed their seeds easily. The legumes belong to the family of plants called Leguminosae or Fabaceae (Whyte, Leissner and Trumble, 1953). They are said to comprise 500 genera and some 11,000 species (Heath, Metcalfe and Barnes, 1973). The most important genera in cultivated forage crops are distributed among the four following tribes (Wheeler, 1950):

Clover tribe (Trifolieae). The true clovers (_Trifolium_ spp.) sweetclovers, and sourclovers (_Melilotus_ spp.), and alfalfa, black medic, and burclover (_Medicago_ spp.);

Lotus trefoil tribe (Loteae). Birdsfoot trefoil and big trefoil (_Lotus_ spp.);

Pea tribe (Viceae). Vetches and horse-beans (_Vicia_ spp.), peas (_Pisum_ spp.), and peavine (_Lathyrus_ spp.);

Lespedeza tribe (Hedysareae) - Lespedeza.

The esteemed position of legumes compared to non-leguminous plants derives from four characteristics.

1. Ability to convert atmospheric nitrogen into organic nitrogen via symbiotic bacteria. This fixed nitrogen becomes available to the legume itself, to any associated plants, and to the crop that follows in a cropping system.

2. Higher nitrogen content: legumes are generally thought

of as having higher feeding value than non-legume forages. They store an abundant amount of protein in their leaves, stems and seeds (Table 1); therefore, they are more desirable for livestock as high-quality hay, in feed mixtures, in silage, and as high-protein supplements than any other plants. They also provide adequate quantities of bone-building minerals such as phosphorus, potassium, and calcium, various vitamins, and growth-promoting substances (Morrison, 1936).

Tables 2 and 3 show a comparison of feeding values between legumes and grasses on the basis of the most appropriate stage of grazing.

3. Flexibility in fitting into special farm practices: in addition to their special value for feed, legumes are superior for soil improvement. They serve as "soil builders," improve soil tilth, and aid in protecting surface soil from erosion. Also, they increase the storehouse of soil nitrogen when they are plowed under properly as green manures, and influence beneficially the numbers, kinds and activities of various desirable soil microorganisms that are important in the decay of organic matter (Heath, Metcalfe and Barnes, 1973).

4. Economic factor: among the essential elements required for continuous and normal plant growth, nitrogen is in most cases the most limiting factor in rangelands because of the ease with which it may be leached from the soil in temperate regions and the comparatively large amount assimilated by plants. These aspects coupled with the inhibiting high cost of artificially replacing it, point out another benefit of legume utilization. Legumes are the cheapest source of nitrogen for maintaining soil fertility and of protein for livestock production.

Table 1. Protein content of seeds, leaves and stems of herbage legumes and grasses (expressed in % of dry matter).[a]

Species	Herbage Legumes			Pasture Grasses		
	Trifolium subterraneum	Trifolium repens	Medicago tribuloides	Hordeum	Phalaris tuberosa	Danthonia semiannularis
Seed	39.63	30.75	22.88	10.50	15.31	17.94
Leaf and stem	9.18	11.50	8.00	3.25	2.69	5.88

[a] Data reported by Whyte, Leissner, and Trumble, 1953. Original source; Waite Agricultural Research Institute, Adelaide, Australia.

Table 2. Comparison of herbage legumes and grasses at flowering and completion of growth (expressed in % of dry matter).[a]

Species	Flowering Stage				Completion of Growth			
	Crude protein	Crude fibre	N-free extractives	Total ash	Crude protein	Crude fibre	N-free extractives	Total ash
Legumes								
Trifolium subterraneum	19.50	22.54	44.92	10.81	12.00	27.88	45.55	8.96
Trifolium repens	21.94	15.76	52.17	9.05	12.31	18.58	60.10	7.75
Medicago tribuloides	29.00	16.23	41.99	11.30	17.19	29.83	43.98	6.52
Grasses								
Lolium perenne	6.25	29.63	53.80	8.87	5.50	27.86	56.72	8.35
Phalaris tuberosa	5.25	33.15	51.53	8.65	4.88	30.27	55.12	7.47
Dactylis glomerata	5.81	25.97	57.02	8.90	5.38	24.64	58.43	8.80

[a] Data reported by Whyte, Leissner and Trumble, 1953. Original source: Waite Agricultural Research Institute, Adelaide, Australia.

Table 3. Comparison of nutrient contents of subterraneum clover and ryegrass (expressed in % of dry matter).[a]

Species	Percentage of Nutrients in Dry Matter							
	N	P_2O_5	CaO	K_2O	Na_2O	MgO	Cl	Soluble Ash
				Legume				
Trifolium subterraneum	3.45	0.61	2.35	4.01	1.54	0.57	1.86	11.83
				Grass				
Lolium perenne	1.72	0.31	0.71	4.53	0.98	0.39	3.55	9.77

[a] Data reported by Whyte, Leissner and Trumble, 1953. Original source: Waite Agricultural Research Institute, Adelaide, Australia.

Economic Botany of Legumes

Morphology of legumes

Legumes are characterized by several important morphological features that differ in many ways from those of grasses. The Leguminosae, or pea family, comprises herbs, shrubs and trees, with alternate, stipulate, usually compound leaves. The flowers may be regular or irregular, usually perfect (Holmgren, 1972). The flowers of the commoner, naturally cross-pollinated species of legumes have corollas characteristically papilionaceous (Whyte, Leissner and Trumble, 1953). The corolla tube varies in length in different species and is a determining factor in the ability of bees and other insects to reach the nectar secreted at its base. These mediators favor the pollination of self-sterile species such as red clover and contribute an extra range income in terms of honey production (Villax, 1963).

A legume is a unicarpellate fruit. The seeds are always enclosed in a characteristic pod. The roots bear nodules containing specific bacteria which play a unique and vital role in the nutrition of these plants (Heath, Metcalfe and Barnes, 1973).

Growth stage and productivity

The feeding value of legumes as well as other plants is greatly influenced by their growth stage at time of harvest. The concentration of proteins, minerals, vitamins, energy, and other nutritional elements, varies from one growing stage to another. This factor must be taken into consideration in the effort to obtain a maximum use efficiency from legume forages.

In leguminous species, growth stages are divided into three major divisions: vegetative growth, flowering and seed formation. The length of each phase varies, depending on legume species, length of season, nutritional level and other environmental factors.

Germination

Two types of germination are characteristic of the legume family: epigeal, in which the cotyledons are pushed above the soil surface, and hypogeal in which the cotyledons remain in position within the seed coat in the soil and the epicotyl, more fully differentiated prior to germination, pushed up through the soil (Whyte, Leissner and Trumble, 1953).

Delayed germination in seed legumes is caused most often by the impermeable seed coat. In addition to this factor, there are others such as an unfavorable environment, and inadequate temperature or moisture (Vallentine, 1974). An inherent facility for rapid germination at a wide range of temperatures and moistures should be of advantage in establishing a legume on rangelands (Young, Evans and Kay, 1970b).

Genetic Resources and Manipulation of Legumes

Breeding

Effective legume breeding investigations have been in progress for more than half a century, and the remarkable improvements that have been attained stand as irrefutable evidence of their benefits to agriculture (Wheeler, 1950).

Breeding objectives fall into three categories (Morley, 1962):

A. Increased value to animals:

1. Through increased intake due to greater acceptability (chemical or physical);
2. Through improved nutritive value, especially in terms of proteins (Milner, 1972);
3. Through increased production and hence availability, at times when intake is often less than needed for maintenance (for example, increased winter growth);
4. Through freedom from harmful structures or substances.

B. Improved ecological adjustment:

1. Adaptation to edaphic factors;
2. Adjustment to climate, especially rainfall, temperature, light, photoperiod, wind, frost resistance;
3. Adjustment to biotic factors, especially severe grazing pressure, competition for weeds, resistance to disease and pests.

C. Agricultural domestication:

Many pasture plants are "wild." There adjustment to agriculture may depend on improvement in attributes such as seed yield, adaptation to harvesting techniques, early vigor and ease of establishment, suitability for fodder conservation, and persistence.

Therefore, in order to cope with the dramatic protein-caloric deficiency existing in the world, particularly in developing countries, legume breeding programs must be extensively encouraged.

The multiplication and expansion of legume improvement programs such as GLIP (Grain Legume Improvement Program, concentrating particularly on forage legume breeding) are still needed in most countries.

Investigation and testing of improved strains

One of the most perplexing problems with respect to legume improvement is to devise methods of testing new source material and new strains that may be developed therefrom. It is axiomatic in plant breeding, introduction and management that the most effective means of testing is one that simulates as nearly as possible the conditions of actual use (Wheeler, 1950). The investigation and testing of improved strains should always start with field trials carried out in several places simultaneously in order to facilitate a local, practical orientation. Care should be taken to test as many different strains as possible to obtain an indication of the amplitude variation within the species and to be able to pick out the most suitable strains.

Introduction and exploitation of legumes

The existing cropping pattern of the world has arisen to a great extent as a result of the progressive introduction and spread over the centuries of plant species into new areas.

The introduction of different plant species is being encouraged, since native plants do not have either real or potential value when compared with artificially sown species, particularly in cases where the native species show an incapability of high production and response to high levels of fertility (Moore, 1973). Moore reported a study on the tablelands of New South Wales, a comparison examining the influence of phosphorus on native and introduced legumes. The four native legumes were of the genera Psoralea, Lespedeza, Glycine, and Desmodium, while the five introduced legumes were all Trifolium spp. The response to phosphorus by the European cloves was 6-fold, while that by native legumes was only 3-fold. Another comparison illustrated in Table 4, made near Uralla, New South Wales, Australia, shows the rate of water use and growth by two communities of native grasses and by a pasture of introduced species, fertilized with superphosphate (Begg, 1959, cited by Moore, 1973).

Although a certain amount of success has already been achieved in the introduction of legumes, the success is not always as great as that which follows the introduction of some non-leguminous plants. This is due to the fact that most of the particular requirements of legumes have not been perfectly understood. Insufficient attention has been given to the importance of root nodule bacteria, inoculation with appropriate strains or to soil deficiencies (Wheeler, 1950). As the scientific research in regard to these factors progresses, the introduction and exploitation of legumes will be intensified. This intensification will have an important effect in breaking the world protein and caloric shortage which progressively increases in relation to the high human population growth rate.

Table 4. A comparison of the growth rates of two communities of native grasses[a] and a pasture of introduced species at Uralla, New South Wales, Australia; data for 2 years (Begg, 1959, cited by Moore, 1973).

Type of Pasture	Minimum Rate of Growth		Maximum Rate of Growth		Mean Rate for All Months	
	Month	lb/acre/day (kg/ha/day)	Month	lb/acre/day (kg/ha/day)	Month	lb/acre/day (kg/ha/day)
Native:						
Bothriochloa macera syn. *B. ambigua*	June-Aug.	<1 (<1)	Dec.	19 (21)		7 (8)
Native:						
Chloris truncata and *Danthonia pilosa*	April-Aug.	<1 (<1)	Oct.	8 (9)		3 (3)
Introduced:						
Phalaris tuberosa, *Trifolium repens*, and *Trifolium subterraneum*	July	8 (9)	Oct.	57 (64)		27 (30)

[a] A third type, characterized by *Sorghum-Themeda*, was shown to occupy a substantially different site.

Poisonous legumes and weeds

Poisonous plants. Poisonous plants cause untold losses each year through death of animals, physical malformations, abortions, and lowered gains (Stoddart, Smith and Box, 1975).

The immense legume family contains some toxic or poisonous plants. Nevertheless, most of them are not dangerous to animals except in large amounts (Vallentine, 1974). Also, their toxicity varies seasonally and depends on the kind of grazer. *Lupinus angustifolius* in *Quercus suber* forests in Morocco is more dangerous after formation of fruits than before and endangers particularly the sheep (Ibnattya, 1972).

As a general rule, poisonous species are not eaten extensively by livestock when other more palatable and harmless species are present. Therefore, good grazing management must be implemented to avoid animal losses by toxicity effects.

Weeds. Generally speaking, a weed is any plant out of place (Vallentine, 1974). The legumes are not bad weeds as a group, but there are exceptions. Under favorable conditions many species, usually considered quite harmless, may turn into pests that are difficult to eradicate. The best example is shown by sweet clover (*Melilotus indica*) in wheat fields in Australia where the importation of its seed is prohibited. In pastures, the shattering habit and natural reseeding ability of many leguminous species--especially the annuals--is very valuable. In crop rotations this is not always the case because some of these valuable species may turn into weeds.

This may happen with bur clovers, hop clovers, and black medic (Whyte, Leissner and Trumble, 1953).

In other special cases, legumes are used by land managers in an attempt to cope with severe competition from weedy annual grasses and forbs. The outstanding example reported by Morley and Katznelson in 1965 shows that the introduced legumes such as clovers represent a desirable counterpart to the many undesirable annual weeds which colonized rangelands in the Western Hemisphere and Australia (Young, Evans and Kay, 1970a).

Range legumes also could be invaded by other weeds. The cheapest and usually the best practical method to reduce this invasion is to follow good range management practices. Chemical weed killers may be adopted in some cases but they have the disadvantages of expense and health hazards. Nevertheless, excellent results have been obtained by the utilization of EPTC (ethyl N, N-di-n-propylthial-carbamate) in establishment of clovers in dryland pastures (Murphy, Kay and McKell, 1962).

Relation to Environmental Conditions

Each legume species, as well as other plant species, has strains adapted to a specific range of climatic and edaphic factors, including air and soil temperature, duration and intensity of light, moisture and aeration of the soil, degree of its acidity or alkalinity, and the availability of specific soil nutrients. Most of these factors do not behave independently.

Climatic factors

Legumes are very sensitive to climatic variations. This sensitivity is due to the fact that the nitrogen fixation is dependent on the rate of carbon assimilation, which in turn is governed by temperature, and duration and intensity of sunlight. In addition to this, temperature and moisture changes have a great impact on activity of soil microorganisms such as Nitrosonomas and Nitrobacter and, therefore, affect the nitrification process by which organic nitrogen already fixed by legumes but unavailable to them is converted to nitrites and nitrates readily available.

Moisture affects not only the yield but also the protein production rate. In moist years, yield is high but the proportion of protein is low and vice versa under dry conditions (Lamborn, 1977).

The growing season for legumes is confined to a portion of the year. This is determined in the first instance by the latitude; as the distance from the equator becomes greater, the period during which growth is possible becomes restricted to fewer months owing to the low temperature and reduced light. Also, as the elevation increases in the tropics, the mean annual temperature falls by approximately 14.7°C for each 300 m (Smith, 1974). This variation in temperature will have an influence on the kind of precipitation and both these factors will be ecological determinants in terms of adaptation of some legume species. Other environmental factors such as aspect or exposure could doubtless be added. This factor also plays an important role in legume species distribution and establishment, since the north face is more moist than the south.

Edaphic factors

The soil factors of particular importance to legumes are the physical capacity of the soil to hold and to release water to the plant, the pH value, the content of necessary nutrients, and the absence of undesirable substances such as soluble salts or organic products which may prove toxic to the legume, or to the rhizobia, on absorption. Any factor which affects growth of the host plant will at the same time affect the amount of nitrogen fixed (Loneragan, 1960). However, the two edaphic factors of major importance in legume distribution are the pH value and the availability of essential nutrients (Whyte, Leissner and Trumble, 1953).

Legumes' tolerance to the acidity or alkalinity of soil varies from one species or variety to another. Alfalfa can grow well in a particularly well-aerated, friable soil in South Australia with an abundance of available calcium. Species of *Medicago* and some of the true clovers are usually found in alkaline soils. Subterraneum clover is definitely restricted to soils which are neutral or somewhat acid and tends to be replaced by species of *Medicago* at pH above 7.0 (Whyte, Leissner and Trumble, 1953). However, it is recommended in legume crops to maintain the soil at a pH around 8.0 in order to favor a maximum nitrification rate (Tisdale and Nelson, 1975).

Apart from nitrogen, the nutrients required by forage legumes are phosphorus, potassium, calcium, magnesium, iron, sulphur, copper, zinc, manganese, boron and molybdenum. All of these nutrients are vitally necessary, some in greater quantities than others, and an excess or deficiency of any one may affect the plant growth or survival according to Liebig's law of minimum. The importance of the trace elements in the establishment of forage legumes has been particularly demonstrated in Australia and India. The workers at Sholapur, Bombay State (J. K. Basu and associates), have produced 100 percent increases in yields of certain legume crops on the semi-arid Deccan by applying small doses of manganese and boron (Whyte, Leissner and Trumble, 1953).

It is very important to maintain a balanced and adequate supply of nutrients in the soils, particularly with cultivated forage legumes since they are desitned to provide a diet rich in protein, calcium, phosphorus and vitamins for domestic livestock, and also to raise soil fertility, and especially the organic matter status of soils exhausted by continuous overgrazing or abusive cropping, or soils naturally low in fertility.

Effects of Legumes on Soil Fertility

The most widespread nutrient deficiency in world agriculture is that of nitrogen and all but a few soils show a moderate to acute deficiency of this element. It may be lost by leaching, volatization and denitrification, asssimilation by plants and removal by animals.

Nitrogen poses a rather different problem from most other nutrients because it is almost wholly contained in the soil organic matter, which in turn moves rapidly towards an equilibrium governed by the pattern of land use and crop production. Any deficiency of nitrogen which may exist at the equilibrium level is therefore less easily resolved on a long term or permanent basis than the deficiency of an element not so fully associated with the organic matter. The application of a few hundred kilograms of phosphorus or a few grams of molybdenum may remedy a deficiency for a long period, but this is not so with nitrogen, which will again move back to the equilibrium level within a relatively short time. For this reason, various agricultural practices have depended for their success either on promoting a satisfactory equilibrum level of organic matter, and thus of nitrogen supply, or on the provision of readily availabile nitrogen for immediate uptake by crops (Donald, 1960). In addition to this important role, nitrogen is also a regulator and governs to a high degree the utilization of some essential minerals such as potassium and phosphorus (Tisdale and Nelson, 1975). Plants deficient in nitrogen are stunted in growth and possess restricted root systems.

Therefore, in spite of the importance of nitrogen, in order to maintain the soil in desirable fertility with continuous availability of nutrients, and to avoid a decrease in crop yield, a regular addition of an adequate amount of nitrogen to soils continuously and abusively used is necessary. This fact, coupled with the inhibitory high cost of artificial nitrogen replacement in the form of commercial fertilizers, underlines the importance of legumes in nitrogen fixation.

Leguminous plants play an unquestionable role in maintaining the fertility of agricultural soils (Mishustin and Shil'Nikova, 1971). Their importance can hardly be denied since it has been estimated that of the 10^8 tons of nitrogen fixed annually, 50 to 80 percent comes from symbiotic fixation in legume root nodules (Tisdale and Nelson, 1975). A report from New Zealand cites that as much as 600 kg of nitrogen per hectare can be fixed in pastures with white clover (Trifolium repens) (Miles, 1957). In Tasmania, some of the permanent pasture legumes such as subterraneum clover, when well established, can provide over 200 kg nitrogen per hectare each year--the equivalent of half ton sulphate of ammonia which would cost about £45 per hectare (Kjar, 1960). Table 5 reports the average amounts of nitrogen fixed by various legume crops (Stewart, 1966).

In addition to the symbiotic nitrogen fixation process made by legumes and their great contribution to the increase of soil fertility, there are, however, other pathways of nitrogen fixation (Kjar, 1960):

From the air, mainly in thunderstorms, small amounts may be gained each year perhaps equal to 4 kg nitrogen per hectare in temperate climes with perhaps five times more in tropical areas.

Fixation by soil organisms and soil colloids. Bacteria in soils such as Azotobacter and Clostridium may fix amounts up to

Table 5. Average amounts of N fixed by various legumes crops.[a]

Legume	Nitrogen fixed (kg per hectare per year)
Red clover	103
Sweet clover	93
White clover	133
Alfalfa	158
Soy bean	84
Mixed legumes	112

[a] Data reported by Stewart, 1966. Original source: "A review of nitrogen in the tropics with particular reference to pastures." A symposium, p. 147. Commonwealth Agricultural Bureau, England. (Bryan, W. W., 1962).

50 kg nitrogen per hectare. Some colloids in the top five centimeters of some soils may absorb plant nutrients from the air although there is still some uncertainty regarding these processes and the amounts of nitrogen so gained.

Fodders from outside sources fed to stock with the dung and urine retained on the land.

Fertilizers and/or farmyard manures used on the land.

Figure 1 illustrates the different sources of nitrogen fixation and Figure 2 shows the nitrogen of the earth, and a partial account of its movement.

As we deal with the role of legumes, the following chapters will concern only the biological nitrogen fixation made by symbiotic process.

Direct effects of legumes on soil fertility: nitrogen fixation by symbiotic process

Historical

The first recorded experimental evidence that legumes could utilize nitrogen from the air was obtained by Boussingault in 1838 (Stewart, 1966). He established the fact that, in the cultivation of clover in unmanured soils, there is a definite gain, not only of carbon, hydrogen and oxygen, but also of large quantities of nitrogen; wheat, however, under the same conditions showed no gain or loss of nitrogen (Waksman, 1927). Hellriegel and Wilfarth demonstrated that such gains of nitrogen in clover took place only

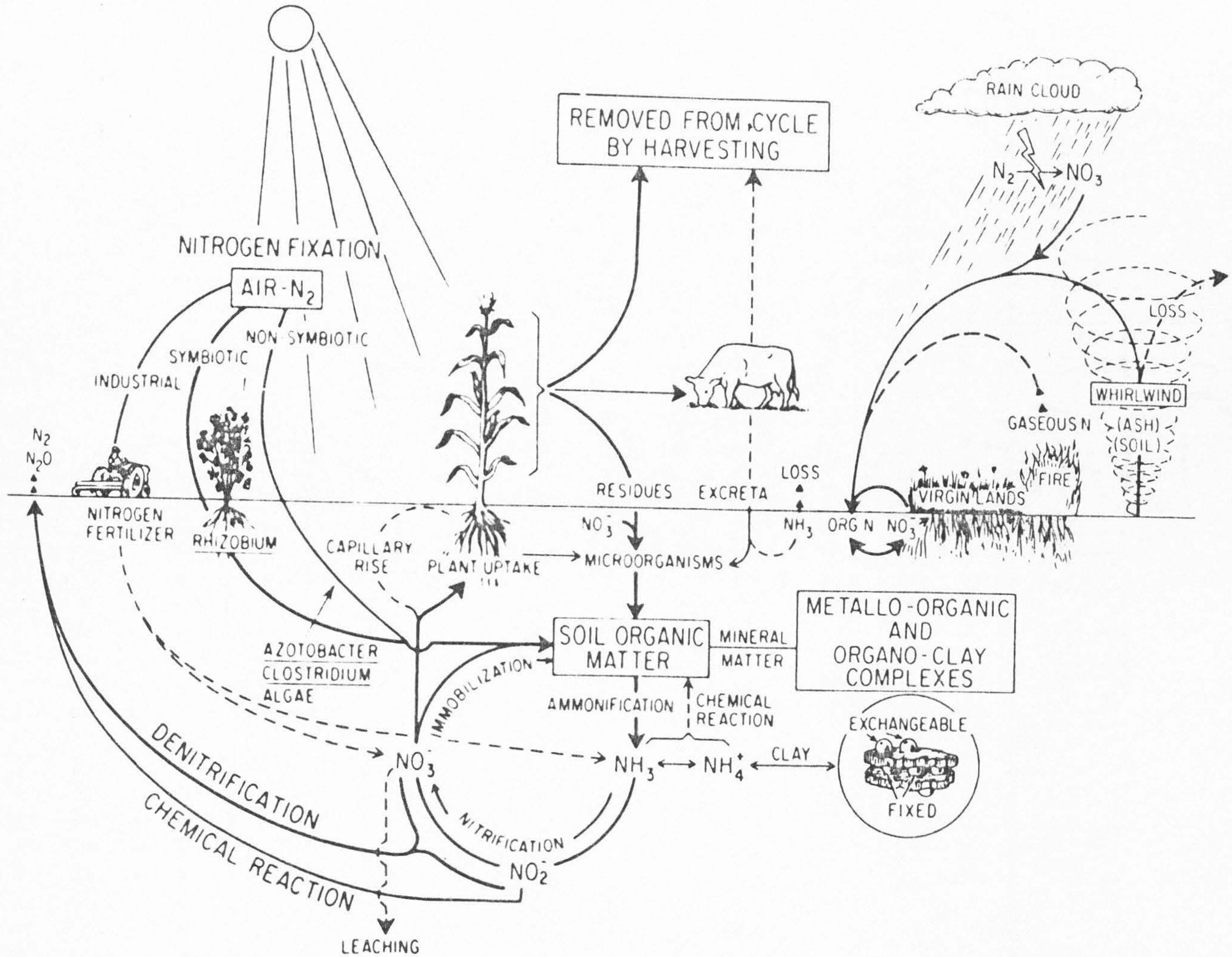

Figure 1. Sources of nitrogen fixation and nitrogen cycle in soil (Tisdale and Nelson, 1975).

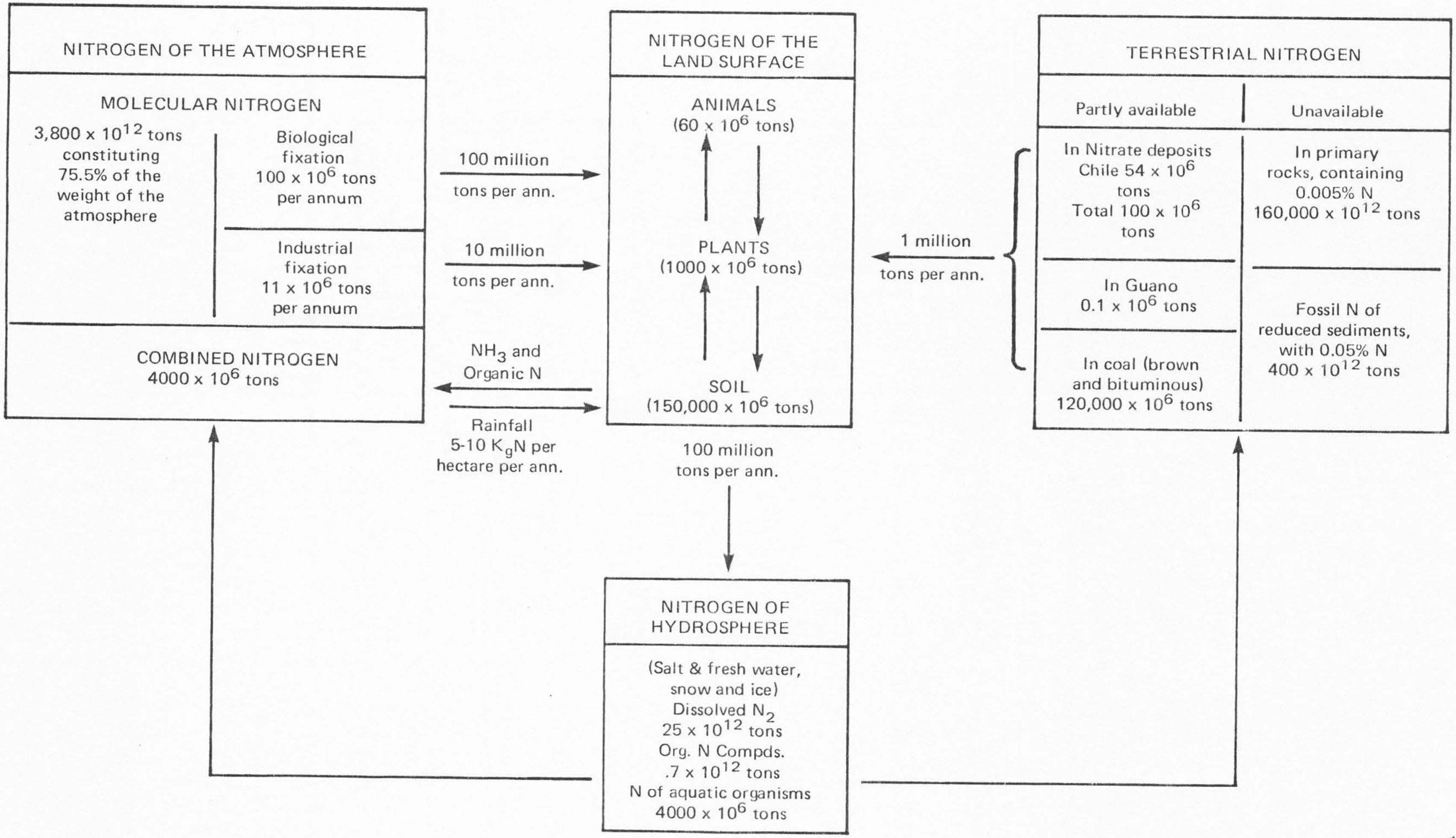

Figure 2. The nitrogen of the earth and a partial account of its movement (Donald, 1960).

in the presence of soil microorganisms and that the root nodules of legumes were intimately concerned. In America, Marshall Ward in 1887 showed that root nodules were formed only in the presence of soil bacteria. The chain of evidence was completed in 1888 by Beinjerink in Holland by the isolation of nitrogen-fixing bacteria from the nodules and from soil, and the specific name Rhizobium radicicola, subsequently changed to Rhizobium leguminosarum, was given to them (Burns and Hardy, 1975).

It can be seen that it is not the leguminous plant itself which is able to "fix" or utilize gaseous nitrogen from the atmosphere, but the bacteria (Rhizobium spp.) in the root nodules. Should the bacteria be absent or ineffective, the plant must still fulfill its nitrogen requirement by drawing upon the nitrogen supply of the soil in the normal way.

Pasture legumes usually contain about twice as much nitrogen per ton of dry hay as grasses; in considering the ability of legumes to contribute to soil fertility it is therefore important that nodulation shall be effective, otherwise legumes may, in fact, deplete reserves of soil nitrogen faster than grasses and cereals. Legumes can only fix nitrogen when they have developed a highly specialized association with specific bacteria. Without the nodule bacterium, or Rhizobium, the legume can grow quite happily but cannot use atmospheric nitrogen. The Rhizobium can also grow freely in soils but likewise cannot fix nitrogen on its own (Loneragan, 1960). Since the symbiotic nitrogen fixation depends upon the successful establishment of a complex union between two free-living organisms, some considerations must therefore be given to assessing the circumstances under which these rhizobia will form the "living together" process or symbiotic association with the leguminous host plant.

Function of the nodule

The earliest conceptions of the nature and functions of legume root nodules tended to regard them as products of some pathological disorders or as storage organs. Atwater in 1886 , demonstrated that these nodules are due to bacterial infection that is beneficial since it is within these nodules that the bacteria fix the atmospheric nitrogen (Waksman, 1927). Recently the isotopic ^{15}N method clarified the whole process of nodule function and nitrogen fixation (Burns and Hardy, 1975).

The nodule is a characteristic feature of most members of the Leguminosae and has nutritional significance. This is particularly true of the subfamilies Caesalpinioideae and Mimosoidea (Boullard, 1967). The nodule production by rhizobia is limited to the Leguminosae family, although certain nonleguminous species such as *Myrica* spp. and *Alnus* spp. produce nodules containing organisms other than *Rhizobium*; their nitrogen fixation rates are low (Stewart, 1966).

The shape, number and distribution of the nodules vary considerably from plant to plant. The total number of nodules on a single plant ranges from a few to several thousand, although the mere presence of numerous nodules is not necessarily a criterion of adequate fixation of nitrogen (Whyte, Leissner and Trumble, 1953).

The bacterial genus, Rhizobium

Rhizobia are motile, non spore-forming, rod-shaped bacteria of the genus Rhizobium, family Rhizobiaceae. All forms are aerobic and have an optimum temperature between 25-30°C. Their growth is particularly affected by pH value (Figure 3). Their number in any soil is diminished greatly by unfavorable environmental conditions, especially inadequate moisture or lack of essential mineral elements such as Ca, P, and K (Heath, Metcalfe and Barnes, 1973). Usually, the more fertile the soil, the greater the numbers of rhizobia it will contain (Whyte, Leissner and Trumble, 1953).

Species relationships and cross inoculation groups

Six Rhizobium species are defined by their distinctive physiological characteristics and ability to form nodules on certain leguminous species. Plants mutually compatible with the same strains of Rhizobia were listed in earlier years in so-called "cross-inoculation groups." This latter term simply means that one is dealing with a recently-developed cluster of species sharing a common degree of physiological specialization (Moore, 1973). Table 6 illustrates the different species relationships.

Development of the nodule

The first step in the formation of the nodule is the invasion of the root by Rhizobium bacteria. Before this happens, conditions must be right for the multiplication of the bacteria close to the surface of the root. The plant assists here by secreting nutrients

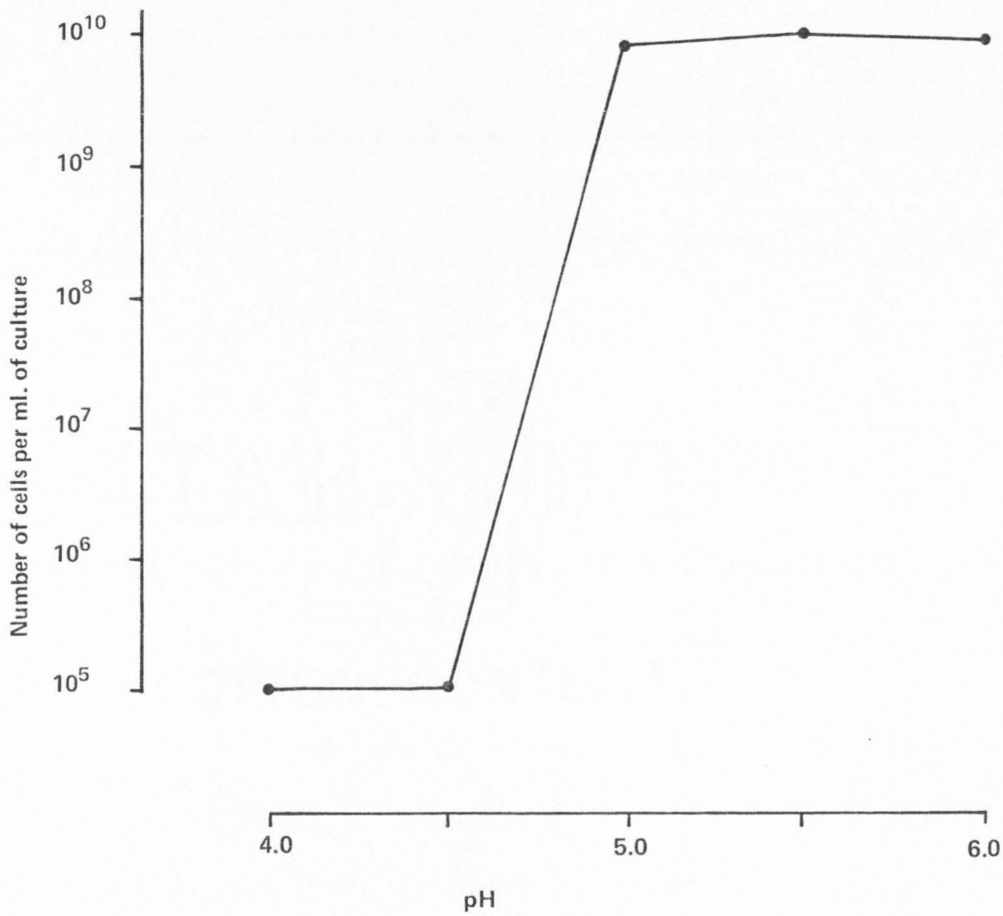

Figure 3. Effect of pH on growth of Rhizobium trifolii strain NA 30. Data reported from J. F. Loneragan, Journal of the Australian Institute of Agricultural Science 26(1): 26. 1960.

Table 6. Species relationships (Whyte, Leissner and Trumble, 1953).

Bacterial Strains	Plant Groups	Genera and Species
1. Rhizobium trifolii	Clover	Trifolium
2. R. meliloti	Lucerne-medick melilot	Medicago, Melilotus, Trigonella
3. R. leguminosarum	Pea	Lathyrus, Lens, Pisum, Vicia
4. R. phaseoli	Bean	Phaseolus (part only) vegetable, navy haricot and case--knife beans
5. R. lupini	Lupine	Lupinus, Ornithopus
6. R. japonicum	Soybean	Glycine
	Cowpea	Acacia, Albrus, Albizzia, Alysicarpus, Andira, Arachis, Baptisia, Cajanus, Canavalia, Clianthus, Crotalaria, Cytisus, Cyampsis, Derris, Desmodium, Dolichos, Enter-olobium, Erythrina, Genista, Hardenbergia, Hymenaea, Indigofera, Inga, Kennedya, Lespedeza, Lonchocarpus, Mucuna, Parkia, Phaseolus (part), Piscidia, Pith-ecellobium, Platylobium, Pongamia, Pterocarpus, Pueraria, Pultenaea, Stylansanthes, Stizolobium, Tephrozia, Ulex, Vigna, Voandzeia
	Strain-specific	Species of Amorpha Amphicarpa Caragana Cicer Coronilla Dalea Lotus Onobrychis Robinia Sesbania Strophostyles

and growth factors. The actual invasion of the root is not a simple matter. It occurs in a remarkable series of events in the root hairs of the plant. There may be other ways that rhizobia can make an entry, for example, through breaks in the root when lateral roots emerge, but the root hair mechanism seems to be by far the most important one. The first thing to happen is the deformation of the root hair by a substance (B-indolylacetic acid) exuded by bacteria congregating in the vicinity. This causes the tip of the root hair to curl. It may well be part of a softening up process; shortly after this occurs an infection thread or tube appears which extends inside the root hair and towards the main part of the root. Although many root hairs may show some deformation only a small proportion of these eventually is invaded. The infection thread contains many bacteria and it grows through the outer layers of cells in the root and releases the bacteria into the interior of certain cells. These are then stimulated into growing into an abnormal swelling that eventually bursts through the wall of the coat and emerges as the growing nodule (Powrie, 1964).

The fully grown nodule contains a mass of cells which are full of bacteria. Cells close to the growing tip of the nodule contain actively growing bacteria, then comes a large central zone where the bacteria are swollen and deformed--the bacteroids--and finally a zone nearest the plant contains disintegrating bacterial cells (Figure 4). A prominent feature of the central zone is the pink color of the tissues due to the presence of haemoglobin. Practical agriculturists know that the color of the nodule tissue tells much

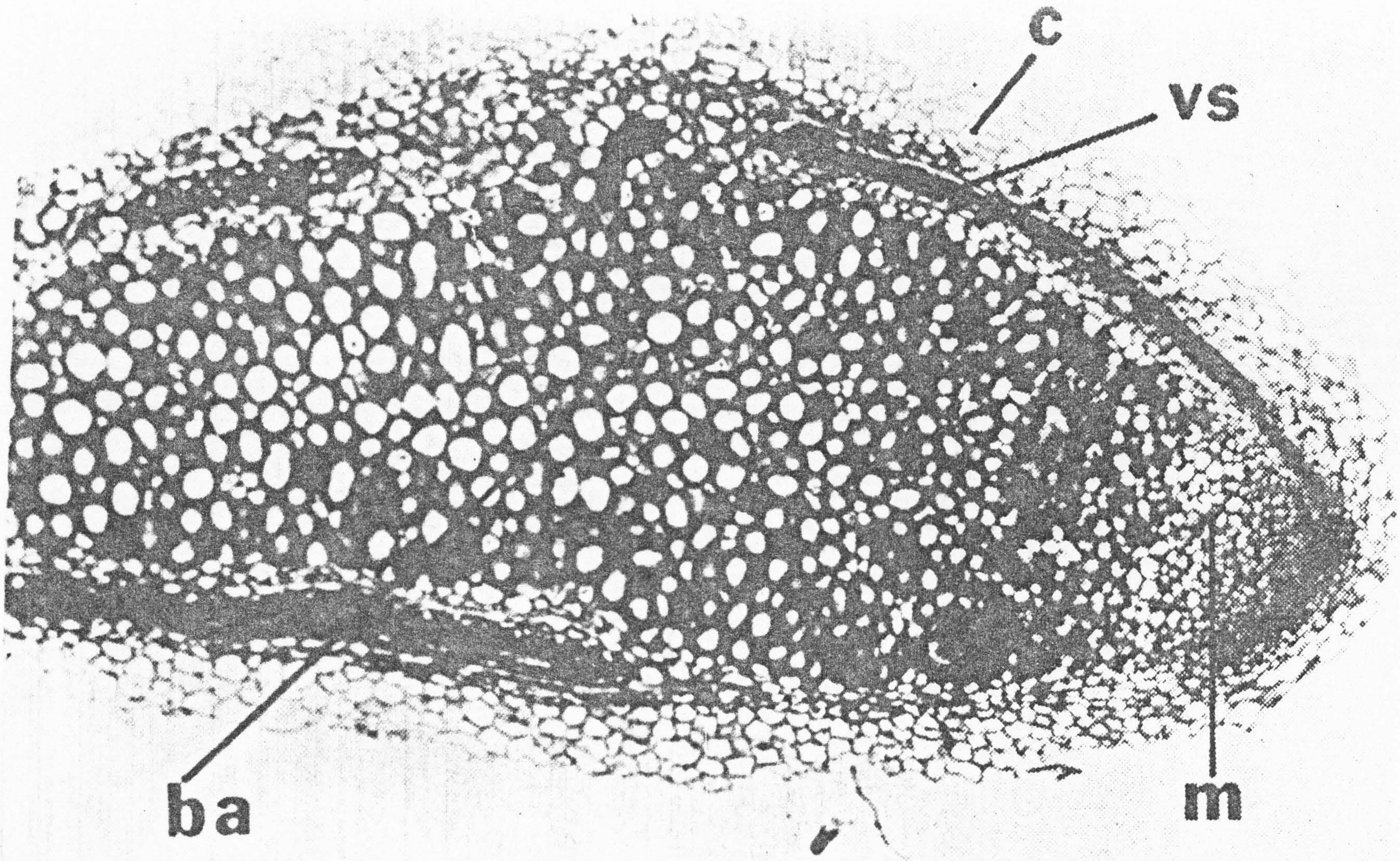

Figure 4. Mature nodule consists of four areas . . . Longitudinal section of an alfalfa nodule showing (c) the cortex, (vs) vascular system, (m) the meristem, and (ba) bacteroid area. Reported from Heath, Metcalfe and Barnes, 1973.

about its effectiveness as a nitrogen fixer. When it is colorless or very pale pink, fixation is not occurring or is very slow, and when the nodule becomes green inside senescence is underway (Powrie, 1964). Figure 5 shows effective nodules on a young pea plant.

Nodulation usually takes place at about the stage of emergence of the first true leaf (Stewart, 1966). The longevity of the nodule is closely related to the growth habits of the host. On herbaceous plants, for example, ineffective nodules begin to degenerate on about the seventh day, but effective nodules may remain intact from five to ten times longer. Nodules may also be lost when eaten by soil predators (Whyte, Leissner and Trumble, 1953).

Factors affecting nodulation and nitrogen fixation

Ineffectiveness of nodulation. Not all nodules fix nitrogen efficiently. Environmental factors can affect the successful establishment of an effective symbiosis between rhizobia and their hosts at any or all of three stages. They may: (1) affect the occurrence, growth and survival of the root-nodule bacteria, (2) modify nodule formation, and (3) affect the functioning of the formed nodule (Bartholomew and Clark, 1965).

Within one cross-inoculation group, strains of bacteria vary in their power to form effective, ineffective, or intermediate associations. Usually this characteristic is the main factor of the value of the symbiotic association. In late 40's Nutman has shown that there are also limiting plant factors which he

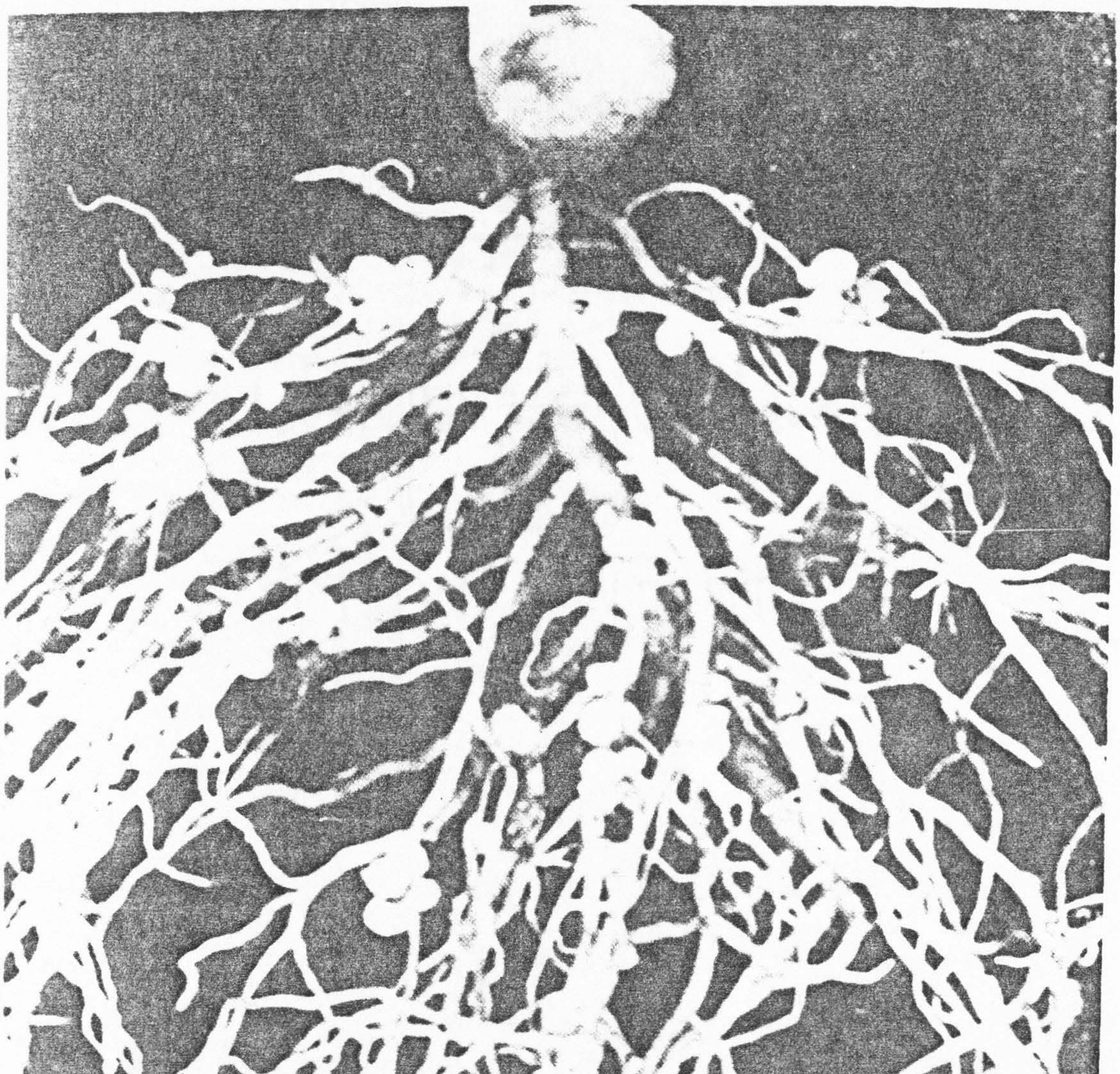

Figure 5. Effective nodules on a young pea plant. Reported by Heath, Metcalfe and Barnes, 1973.

terms "responsive" or "unresponsive" and which are determined by genetic factors (Whyte, Leissner and Trumble, 1953).

Barriers to nodulation and nitrogen fixation. Many factors may also affect nodulation and nitrogen fixation, among which the most important are: toxic factor in seed coat, desiccation, contact with fertilizers, and insecticides and soil factors.

Toxic factor in seed coat. Recent work has shown that bacteria in the inoculum need protection not only from the outside environment but also from a toxic substance that is released from the seed coat of some legumes such as subterraneum clover. Pelleting with lime or some other means of reducing direct contact of bacteria with the seed coat will result in improved survival.

Desiccation. Drying leads to very sudden mortality of bacteria and is the basis for the recommendation that seed be sown into moist soil.

Contact with fertilizers and insecticides. Acidic fertilizers such as superphosphate can effectively sterilize seed after a short period of contact and when inoculation is necessary that practice of sowing seed and 'super' together can lead to disastrous results. The trouble can be avoided by using neutralized or basic super or sowing the seed separately from the fertilizer.

Soil factors. The most important edaphic factors influencing the nodulation are: acidity, carbon/nitrogen ratio, and the supply of phosphorus, calcium, magnesium, molybdenum and cobalt in the soil.

In considering the acidity effect, there is clear evidence that nodulation is severely reduced in most leguminous species when pH is below 5. Liming is the answer to acidity problems (Powrie, 1964).

The factors affecting the ratio of C to N in the soil are close to those influencing the rate of photosynthesis. An increase in light intensity or in partial pressure of carbon dioxide in the atmosphere will tend to increase the rate of fixation. With increasing carbohydrate, invasion of the plant and fixation of nitrogen are increased; with increasing nitrogen these functions decrease (Figure 6) (Wilson, 1940). A high level of combined nitrogen in the soil will prevent deformation of the root hairs and hence entry of the bacteria will be precluded and no nodules formed. Where there is little or no available nitrogen in the soil and the plant is entirely dependent upon symbiotic fixation, the plant enters a period of "nitrogen hunger," when all the reserves in the seed are utilized. This period generally lasts only about a week, or longer, if the symbiotic system is not readily developed. To shorten this period of nitrogen starvation, it is desirable artificially to inoculate the seed with rhizobia so that there is no undue delay in nodule development due to absence of organism. The wider the carbon/nitrogen ratio becomes, due to any of the causes indicated previously, the greater is the degree of nodulation (Whyte, Leissner and Trumble, 1953).

Thus, in summarizing, it is apparent that the carbohydrate/

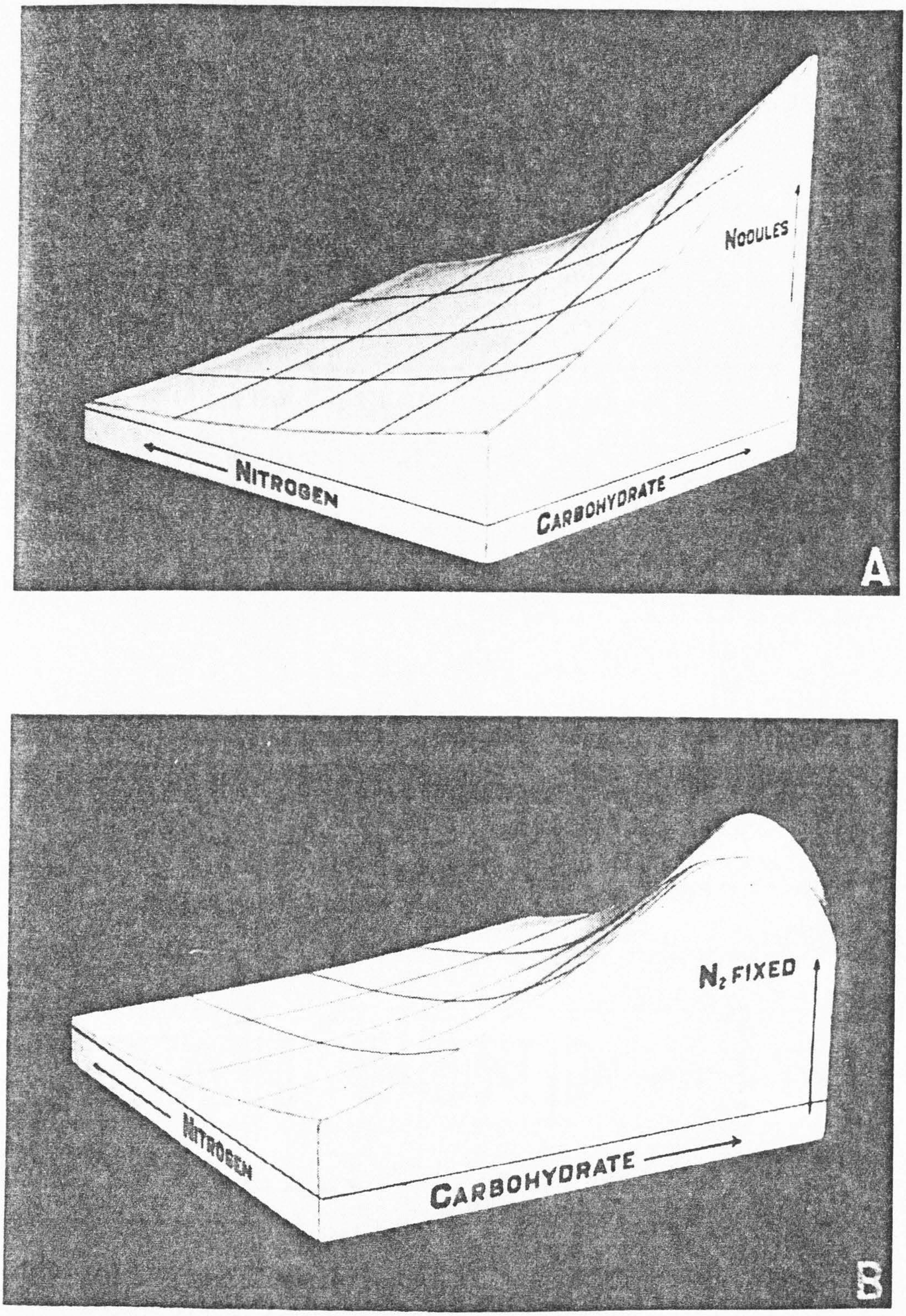

Figure 6. Diagrammatic models representing (A) invasion of plant and (B) fixation of nitrogen as a function of the carbohydrate-nitrogen relationship in the host plant. With increasing carbohydrate, invasion of the plant and fixation of nitrogen are increased; with increasing nitrogen these functions decrease. A maximum region is reached on the surface illustrating fixation of nitrogen. Figure reported by Wilson, 1940.

nitrogen ratio and other internal factors, possibly including growth substances, affect nodulation and fixation.

Legumes require more phosphorus fertilizer than grasses. This is due to the fact that the legume has less soil absorption efficiency than the grasses (Lamborn, 1977).

Phosphorus represents another important element influencing symbiotic nitrogen fixation. The rate of protein synthesis is low in soils deficient in phosphorus. This element has also an effect in the earlier infection stages of nodulation and plays a great role in maintaining the rhizobial population at a high level in the soil. There is some evidence that on lateritic podzolic soils in Southern Australia, heavy additions of superphosphate are necessary to maintain the rhizobial population at such level that failure of clover will not take place in the second and subsequent years in legume-based sown pastures (Moore, 1973).

With respect to the roles played by calcium and magnesium, a complete reappraisal of this subject has resulted from Australian research. The traditional view, based largely on the work of McCalla in 1937, was that rhizobium is a calcium-hungry organism and that the concentration of available calcium needs to be relatively high to sustain and achieve a high rhizobial population (Moore, 1973). The calcium content of legumes is about three times that of grasses on the basis of weight of dry hay. Consequently, a leguminous crop may respond to liming where a non-legume may not (Whyte, Leissner and Trumble, 1953).

Magnesium seems to play a closely analogous role, possibly in part because calcium is rendered more available in its presence. Neverthess, Vincent in 1962 demonstrated that the Ca:Mg ratio of 1:8 in the soil should be maintained for perfect nodulation (Moore, 1973).

Molybdenum plays an important role in the nitrogen fixation process. Anderson in 1942 reported an outstanding example in the meadows district of South Australia where subterraneum clover pasture on ironstone soils remained very poor despite liberal application of superphosphate. It was noticed that improved growth occurred where timber had burned, and the application of wood ashes reproduced this effect. Patient elimination of other nutrients led to molybdenum, and finally the application of 1 kg of ammonium molybdate per hectare gave spectacular yield increases. Subsequent work (Anderson and Moye, 1952) clearly established the basic facts that molybdenum affects the functioning of symbiosis within the nodule, not the formation of nodules, and its availability in soils is a function of pH, the effect of lime being to release molybdenum. Beginning in 1951, superphosphate premixed with molybdenum has been available on the Australian market for pasture development. The present consumption being estimated to lie between 300,000 and 500,000 tons per annum (Moore, 1973).

Cobalt is also required by rhizobia for nitrogen fixation. It contributes also to the formation of vitamin B_{12} (Lamborn, 1977).

Inoculation

Necessity for seed inoculation. No agricultural soils contain the necessary legume bacteria to promote the maximal growth of legumes. In some cultivated soils, the legume bacteria naturally present are of mediocre or relatively ineffective type of nitrogen fixers. For example, in Wisconsin one hundred soybean fields were examined and nodules collected for isolating the soybean bacteria. When these strains were tested on soybeans, it was found that 25 percent were considered highly effective, 50 percent were only average, and the rest were poor or ineffective. Even though the bacteria for a certain legume may be present in a given soil, the question always arises, are they there in sufficient numbers and are they the high nitrogen-fixing strains? Therefore, the inoculation practice has proved in most cases necessary. There is good sound advice to all farmers, "inoculate in all cases of doubt and always in new land" (Wheeler, 1950).

The one fundamental purpose of legume inoculation is to add a fresh culture of effective strain of legume bacteria to the seed (preferably), so that when the young plant begins to grow, the bacteria will be right there to enter the tiny root hairs and begin their beneficial work in the early stages of the plant's growth. Early practices entailed the transfer of soil from a field where a particular plant had grown satisfactorily to the area where a leguminous crop had failed for need of N, or the transfer of soil to new land being opened for legume culture. This practice was followed by the bulk culture of the proper rhizobia on agar, in liquids, and in peat-based mixtures. This latter preparation is sold as a separate package and applied by the farmer to the seed immediately before planting (Heath, Metcalfe and Barnes, 1973).

The innovation of "preinoculation" or "preinoculated seed" appeared in the early 1960's (Bartholomew and Clark, 1965). This practice involves the treatment of leguminous seed with rhizobia by seed processors, distributors and dealers months in advance of planting. It embodies two widely different procedures of seed treatment. One process consists of spraying the seed with a broth culture or a reconstituted concentrate of rhizobia followed by subjecting the seed mass to a vacuum treatment. It is claimed that the rhizobia impregnate the interior of the seed, that they are protected against adverse environmental conditions, and that they remain viable for long periods. The other basic process, of which there are variations, entails coating the seed with rhizobia that are usually contained in a peat-based slurry. In the peat-based rhizobial mixture are gums, sugars, and high molecular polysaccharides that provide adhesive and protective properties (Heath, Metcalfe and Barnes, 1973).

Benefits of legume inoculation. Inoculation of legume seed is a simple and economical method of obtaining N. Table 7 shows the low cost of inoculating leguminous seed in the U.S. Benefits obtained from legume seed inoculation are fourfold (Figure 7).

1. Early formation of effective nodules is insured. Rhizobia added to the rhizosphere by means of the seed bring about immediate

Table 7. Cost of inoculating leguminous seed in the U.S.[a]

Species	Rate of Seeding (kg/ha)	Cost per ha		Total Cost per ha ($)
		Inoculant ($)	Labor[b] ($)	
Alfalfa	16.80	0.42	0.20	0.62
Birdsfoot trefoil	5.60	0.15	0.07	0.22
Hairy vetch	45.00	1.05	0.55	1.60
Lupine	84.00	1.18	1.01	2.19
Soybeans	56.00	0.30	0.67	0.97
White clover	2.25	0.05	0.03	0.08

[a] Data reported from Heath, Metcalfe and Barnes, 1973). Original source: Burton, J. C. 1907. Rhizobium culture and use. In H. J. Peppler (ed.), Microbial technology, pp. 1-33, Reinhold, New York.

[b] Labor is calculated at $2.00 per hour; 10 minutes is the time required to inoculate 27 kg of seed by hand. Machine application enables a saving in cost of labor.

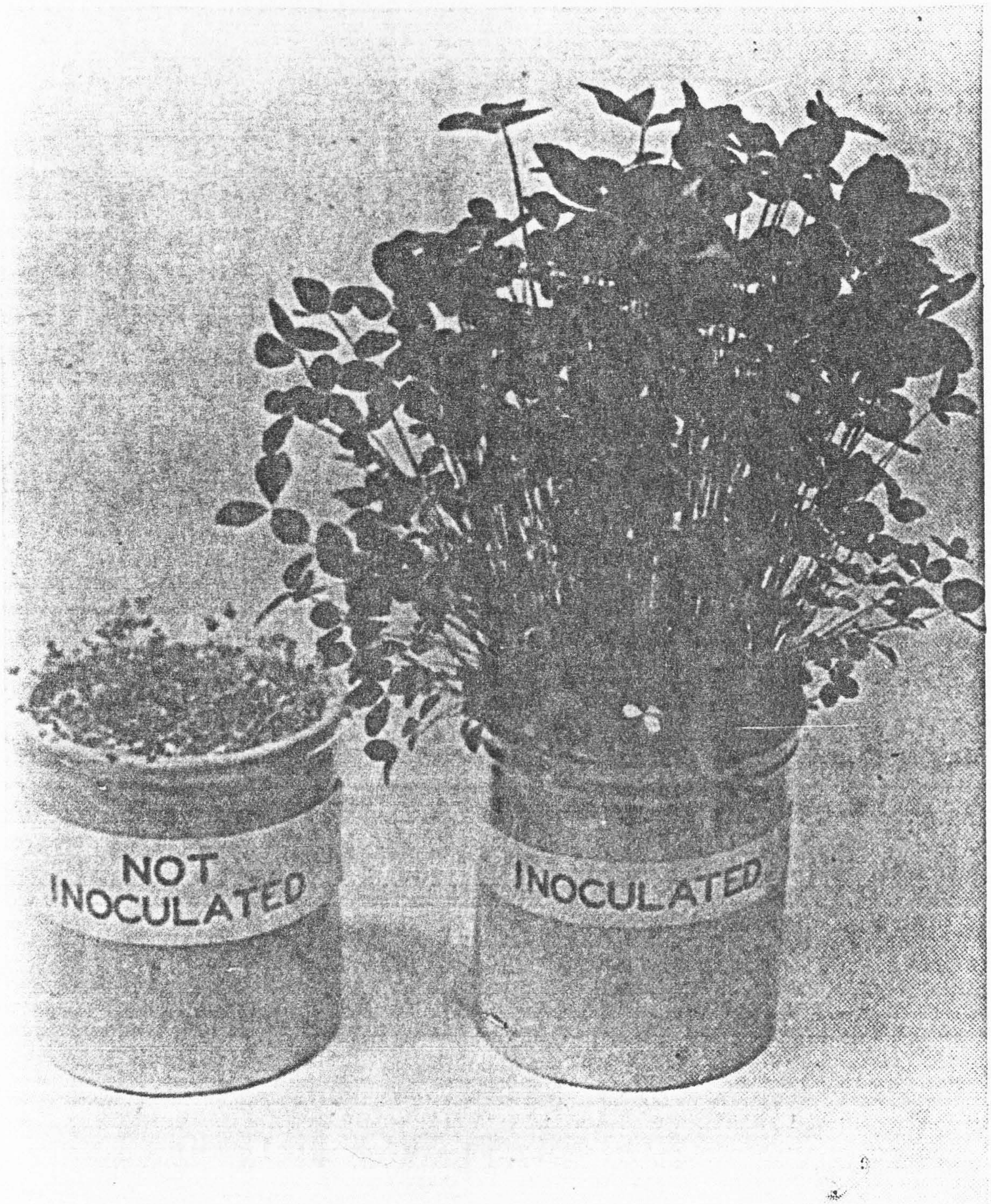

Figure 7. Benefits from inoculation are fourfold. Effective inoculation of red clover. Nitrogen was supplied to the inoculated plants by effective rhizobia. All plants received a balanced, N free, nutrient solution (Heath, Metcalfe and Barnes, 1973.

infection. Table 8 shows the effectiveness of inoculation of legumes in field experiments in the U.S.S.R.

2. An adequate supply of N becomes available to the plant soon after the seed protein supply is exhausted. Accordingly, N hunger is short-lived if it occurs at all.

3. Good effective inoculation has been a controlling factor in increasing the yield and quality of legume crops. It makes possible greater quantities of high protein feeds so necessary in the production of livestock. Yield increases of 10-15 percent are usual but may attain 25 percent or more on poor land. In addition, the chances to obtain a good crop stand are greatly improved. Table 9 shows the effects of inoculation of soybeans on yield, where the gain for the pea crop reached 40 percent.

4. Soil N is conserved subsequent to the turn-under of the N-rich, succulent, readily decomposable, leguminous green manure; the soil reservoir of nutrients is augmented; and tilth is improved.

Distribution of nitrogen in legumes

The amount of N fixed by properly nodulated legumes averages about 75 percent of the total N used in the growth of the plant. The amount of N fixed by short-period annual legumes varies between 56 and 112 kg/ha/year. The amount fixed by perennial legumes is higher. Factors making for optimum legume growth influence the quantity of fixed N. This quantity varies greatly from crop to crop and from legume to legume. In general, the N content of leguminous roots is about equal to the amount of N absorbed from

Table 8. Effectiveness of inoculation of legumes in field experiments in the U.S.S.R. (data are for 1958-1963).

Crop	Character	No. of Tests	Test With Positive Results %	Mean Harvest in Controls 100 kg/ hectare	Increase in Harvest	
					100 kg/ hectare	%
Pea	Green matter	8	75	123.2	29.1	23.5
	Seed	24	83	16.7	2.5	14.9
Broad bean	Green matter	10	90	171.5	29.3	16.6
	Seed	6	66	16.8	3.1	18.0
Lupine	Green matter	14	100	232.9	156.1	66.1
	Seed	9	100	10.5	2.2	20.9
Soybean	Green matter	2	100	79.5	15.5	19.1
	Seed	26	70	12.9	1.6	12.3
Chickpea	Seed	6	100	13.4	2.1	14.9
Alfalfa	Hay	4	100	45.7	12.4	26.9
	Seed	3	100	1.9	1.1	57.9
Sainfoin	Hay	4	100	35.9	11.2	31.1
	Seed	3	100	6.0	2.8	46.6

Statistical treatment showed the gains to be significant.

Data taken from Mushustin and Shil'Nikova, 1971.

Table 9. Effect of inoculation of soybeans on yield.[a]

Experiment variant	Yield (100 kg/hectare)	No. of nodules per plant	Weight of 100 seeds (g)	Content of protein in beans, % in relation to absolutely dry matter
Controls	16.5	0.4	136	35.9
Inoculation with culture:				
638	19.6	39.0	156	41.1
640	20.8	49.0	158	42.2

[a] Data from Mishustin and Shil'Nikova, 1971.

the soil. Only about 33 percent of the N of plants with long taproots is returned to the soil by decay of the root systems. The distribution of N in plant parts of two species each of alfalfa and clover is shown in Table 10 (Heath, Metcalfe and Barnes, 1973).

Table 10. Distribution of N in four leguminous species.[a]

Species	Percentage of Total N		
	Tops	Roots	Nodules
Subterraneum clover	69-85	11-21	3.6-12.6
White clover	81-84	11-14	3.5-4.4
Alfalfa	50-66	29-43	4.5-12.5
Barrel medic	80-82	13-15	3.4-7.2

[a] Table reported from Heath, Metcalfe and Barnes, 1973. Original source: Jensen, H. L. and D. Frith. 1944. Production of nitrate from roots and root nodules of alfalfa and subterraneum clover. Proc. Linnean Soc. N.S.Wales 69:210-14.

Indirect effects of legumes

Root systems

In reviewing the effects of legumes on soil fertility one must take into consideration the nature of the root systems of the various species. These are important in relation to the effect of legumes on nitrogen content and organic matter status of the soil, on soil structure, on associated grasses, and on the yield and vigor of succeeding crops (Whyte, Leissner and Trumble, 1953).

It is known, however, that there are great differences in root penetration, from the subsoil exploration by means of the prominent taproot of some leguminous species such as sweet clover and alfalfa to the shallow though well-branched root systems of others such as subterraneum clover or white clover. Depth of penetration of the root system is a vital factor in relation to drought resistance. T. B. Paltridge in Australia has shown that alfalfa can develop a root system which will explore the soil mass to depths of 5.5 to 6 m. In cultivated rows, alfalfa roots spread horizontally at least 3.6 m from the row itself and appear to explore effectively and occupy all but the surface 7.6 or 10.2 cm (Whyte, Leissner and Trumble, 1953).

Legumes themselves may not develop soil structure to anything like the extent possible with grasses, but grasses may depend upon associated legumes for the nitrogen required to develop the type and extent of root system which greatly improves soil structure. The deep rooted plants may also have important subsoil effects, as in Melilotus alba.

Green manures

The value of green-manure crops, particularly legumes, was also soon recognized. Lupine was quite popular with most of the test animals (Tisdale and Nelson, 1975).

The introduction of leguminous plants as green manures in sward soils affects chiefly the following: physical, chemical and biological conditions of the soil (Waksman, 1927).

Soil temperature. The addition of 50 tons of manure per hectare may give an average increase of 5°C in the temperature of the soil. This increase affects the soil microbial activities, nitrification process, and decomposition of organic matter.

Soil moisture. Green manure, incorporated into the soil, improves the soil structure and the moisture holding capacity of the soil due to the accumulation of organic matter.

Soil atmosphere. The rapid decomposition of manure added to the soil results in the formation of large quantities of CO_2, which will tend to improve the physical condition of the soil giving it a crumbly appearance, giving rise to higher pH, and hence will increase the availability of some mineral elements, particularly phosphorus (Tisdale and Nelson, 1975).

Reaction and buffer content of the soil. The decomposition of nitrogenous substances, leading to the formation of ammonia and nitric acid on the one hand, and the decomposition of the carbohydrates which may lead to formation of some organic acids on the other hand, are important in this connection.

Introduction of readily available energy. Introduction of readily available energy, as well as of nitrogen and minerals, will in itself greatly stimulate bacterial activities.

The introduction of leguminous species into the pasture soils as green manure is effective in aiding organic matter production and maintenance (Horner, Overson, Baker and Pawson, 1960). Neverthless, careful analysis of the C:N ratio must be taken into consideration. This ratio must be maintained in the range 10:1 to 12:1 and must never exceed this value, otherwise the nitrogen fixed will be immobilized (Lamborn, 1977).

Mixed cropping

Mixtures of plants, grasses and legumes particularly, are considered most satisfactory for pastures (Wheeler, 1950). This practice used in farm management for many centuries has many advantages (Wilson, 1940).

Economical use of land and efficient agronomic management. If two crops of unlike kinds be sown together, their roots absorb the inorganic substances in different propotions. Thus they interfere less with each other than plants of the same kind do, which require the same kinds of nutrients in nearly the same proportions. Or the two kinds of crops grow with different degrees of capacity, or at different periods of the year; and thus, while the roots of the one are busy drawing in supplies of inorganic nourishment, those of the other are comparatively idle; and thus the soil is able abundantly to supply the wants of each as its time of need arrives.

Balanced ration. Some pasture crops are grown as food for livestock animals; a mixture of legume, high in protein, and of nonlegume, high in starch, provides a more balanced ration than either crop alone, particularly due to the fact that the animals prefer to graze a variety of species.

Possible substitute for rotation. Agricultural research has established the fact that continuous use of a field for a single crop results in the deterioration of the soil, even when mineral fertilizers are added. Rotation of crops, especially when a legume is included in the rotation, appears sometimes to be fairly efficacious in maintaining crop yields.

Excretion of nitrogen. For many years, observers suggested that the advantage of crop mixtures that include one or more legumes may be related to the capacity of such plants to excrete into the soil a portion of the atmospheric nitrogen fixed by them.

The nitrogen fixed by herbage legumes is gained by associate grasses largely following ingestion by the animal and subsequent excretion of nitrogen as urea and its breakdown products in the urine. The root systems of legumes are not capable under field conditions of excreting substantial quantities of soluble nitrogenous products into the soil for subsequent absorption by associate grasses. Investigations have revealed, however, that the root systems of legumes contain at any given time only a small proportion of the nitrogen fixed, most of this being translocated to the leaves and fruits. Even the small proportion remaining in the roots does not usually become available in the soil until the root nodules and fine rootlets disintegrate or the plant as a whole dies, whereupon the roots break down and release their nitrogen for use by other plants (Whyte, Leissner and Trumble, 1953).

There are many other questions associated with the composition and establishment of seed mixtures which depend largely on local conditions and farming practices (Wheeler, 1950).

Fertility cycle

Full utilization by the grazing animal of the legume and its associate grasses in herbage mixtures represents the basis of grassland farming in many countries, particularly Australia, New Zealand, and Great Britain. The system merits full investigation in all countries in which it is not already practiced. It is the cycle of crop/animal/soil/crop in full operation (Whyte, Leissner and Trumble, 1953).

A well-balanced and correctly managed pasture containing a mixture of legumes and grasses is an excellent source of palatable high-protein grazing in these relatively restricted parts of the world in which they can be grown successfully. The two important factors are the legume, generally white clover or subterraneum clover (winter rainfall environments) in the mixture, and the presence of the grazing animal as an "implement" in the fertility cycle, particularly under conditions where high rates of stocking and long grazing periods can be achieved. It is necessary to consider the nature of the livestock, whether growing, fattening, or dairy beasts, and to replace, through fertilization, the soil nutrients which they remove in the type of animal product for which they are kept. One must also consider losses of nutrients through leaching (Whyte, Leissner and Trumble, 1953).

The removal of legumes and their associated grasses from the field for feeding green or for conservation in the form of hay, silage or dry green crop, presents quite a different picture. The crop/animal/soil/crop cycle is broken by the absence of the grazing animal; its removal may be compensated to some extent by the return of all stable and liquid manure to the same land. The harvesting of a heavy green crop therefore entails the removal of considerable quantities of soil nutrients, which should in due course be returned to the soil in the form of artificial fertilizers. Under an all cutting regime on soils of low to average fertility, this may become quite an expensive item in terms of phosphate or potassium fertilizers (Whyte, Leissner and Trumble, 1953).

Utilization of Legumes

Legumes in rotation

There are in all parts of the world examples of field rotations in which crops that remove fertility from the soil alternate with those restoring fertility in the form of nitrogen, organic matter, crumb structure, microbiology, and soil health. We know that it is necessary for the recovery or resting break to have a legume in its composition, generally in association with a grass, and that under favorable conditions of soil and climate the greatest benefit can be obtained if the herbage growth is grazed in situ (Whyte, 1953; Leissner and Trumble, 1953).

In general, crop rotations including legumes result not only in high crop yields but also in maintaining soil organic matter, furnishing good protection against runoff and erosion, and maintaining higher rates of infiltration of water into the soil, probably as a result of improved soil structure.

Effects of crop rotations on crop yields. Usually rotations with legumes or legume-grass crops for green manure or hay result in higher crop yield than continuous single grass species or grass-fallow. Table 11 reports the experimental results of the effect of crop rotations on crop yields at Pendleton, Oregon (Horner, Overson, Baker and Pawson, 1960).

Crop rotations have also a great effect on the yield of succeeding crops. Table 12 illustrates the effect of alfalfa and grass on yields of succeeding crops (Horner, Overson, Baker and Pawson, 1960).

Effects of leguminous organic materials on the yield. Some of the effects of crop rotations on crop production are associated with the application of organic material in the form of crop residues and green manures. Table 13 reports the experimental results of the effect of leguminous organic materials on the yield of wheat (Horner, Overson, Baker and Pawson, 1960).

Effect of crop rotations on erosion losses. Table 14 illustrates the effect of crop rotations and winter cover conditions on erosion losses, and shows that the differences in the amount of runoff for the crop rotation plots for some of the cover conditions were probably associated with changes in soil structure induced by the crop rotation treatments. The relationship was most clearly shown by the results obtained for the winter wheat after peas cover condition (Horner, Overson, Baker and Pawson, 1960).

The utilization of legumes in crop rotation in ranges depends on many factors including the economical and technical status, and the ecological conditions. Farmers dependent primarily on livestock and livestock products for their living, and using sown swards or

Table 11. Effect of crop rotations on crop yields at Pendleton, Oregon.[e]

Rotation and Crop	Period covered by data	Yields, tons/ha	
		Rotation	Check
Alfalfa (3 yrs)-Fallow-W.Wheat-Corn			
Alfalfa, 1st year	1931-53	1.1[c]	
Alfalfa, 2nd and 3rd years	1931-53	3.4	
W. wheat after fallow	1934-53	1.6	3.2[a]
Corn after wheat	1935-53	1.6	0.9[a]
Peas and Sweetclover-Green Manure-S. Wheat-Fallow-W. Wheat			
Peas with sweetclover	1944-53	1.4	1.8[b]
S. wheat after green manure	1946-53	2.7	2.9[c]
W. wheat after fallow	1948-53	3.2	2.8[d]
Sweetclover-Green Manure-S. What-Fallow-W. Wheat			
S. wheat after green manure	1946-53	2.7	2.9[c]
W. wheat after fallow	1948-53	3.6	2.8[d]
Sweetclover+Grass-Green Manure-S. Wheat-Fallow-W. Wheat			
S. wheat after green manure	1946-53	2.6	2.9[c]
W. wheat after fallow	1948-53	3.5	2.8[d]
Pea Green Manure-W. Wheat-Fallow-W. Wheat			
W. wheat after pea green manure	1939-53	3.3	2.9[d]
W. wheat after fallow	1939-53	3.4	2.9[d]
Pea Green Manure-S. Wheat-Fallow-S. Wheat			
S. wheat after pea green manure	1939-53	3.1	3.0[c]
S. wheat after fallow	1939-53	3.2	3.0[c]
Peas-W. Wheat			
Peas after w. wheat	1931-53	1.6	3.2[d]
W. wheat after peas	1931-53	2.2	
Peas-W. Wheat			
Peas after s. wheat	1931-53	1.6	
S. wheat after peas	1931-53	2.3	3.0[c]

[a] Winter wheat-corn-spring wheat-fallow.
[b] Winter wheat-peas.
[c] Spring wheat-fallow
[d] Winter wheat-fallow
[e] Data reported by Horner, Overson, Baker and Pawson, 1960.

Table 12. Effect of alfalfa and grass on yields of succeeding crops.[a]

Sequence of crops grown after alfalfa and grass	Period covered by data	Tons per hectare yield of crops when grown after:			
		Alfalfa	Alfalfa & grass	Grass	Check[a]
Clay Hilltop, Moscow, Idaho[b]					
First: wheat	1942, 1946	3.35	3.24	1.89	1.26
Second: wheat	1943, 1947	3.34	3.04	1.47	1.08
Third: wheat	1944, 1948	1.72	1.82	1.21	0.81
Fourth: wheat	1945, 1949	1.56	1.47	1.44	1.05
Average	1942-49	2.49	2.40	1.50	1.05
Alfalfa-Grass Plots, Pullman, Washington (ARS)[c]					
First: wheat	1948-49	3.37	2.81	2.99[d]	2.56
Second: peas	1949-50	1.50	1.63	1.51	1.36
Third: wheat	1950-51	3.14	3.15	2.42	2.10
Average (wheat)	1948-51	3.25	2.98	2.71	2.33
Alfalfa-Grass Plots, Moro, Oregon[e]					
First: wheat	1946	1.43	1.73	1.89	2.10
	1947[f]	0.22	0.39	1.06	0.81
Second: wheat	1948-49	2.58	2.46	2.47	2.27
Third: wheat	1950-51	2.51	2.42	2.40	2.19
Fourth: wheat	1952	2.74	2.83	2.57	2.57
Fifth: wheat	1954	2.28	2.43	2.07	1.96
Average	1946-54	2.19	2.24	2.19	2.09

Table 12. Continued.

[a] Check treatments: continous wheat at Moscow, wheat after peas at Pullman, and wheat after fallow at Moro.

[b] Soil had a low organic matter content. On plots cropped to wheat in 1942, alfalfa and grass had been grown for 4 years. In 1946, wheat was planted on land that had been in alfalfa and grass for 8 years.

[c] Data are averages of plots that were cropped 3 years and 5 years to sod crops.

[d] Fertilized at rate of 40 kg per hectare of nitrogen each year grass was grown and at time grass was plowed.

[e] Alfalfa and grass crops were grown 5 years, sod was spring plowed and fallowed, and land then seeded to wheat and fallowed in alternate years.

[f] The 1947 crops received abnormally low precipitation.

[g] Data reported by Horner, Overson, Barker and Pawson, 1960.

Table 13. Effect of leguminous organic materials on the yield of wheat.[b]

Location and crop	Period covered by data	Organic material applied: Kind	Organic material applied: Amount t/ha	Yield of wheat: With organic material t/ha	Yield of wheat: Without organic material t/ha
Field 3, Pullman (WSU)					
Continuous wheat	1922-52	Alfalfa hay	3.08	2.23	1.61
Wheat after fallow	1922-52	Alfalfa hay	3.08	3.34	3.23
Sweetclover Plots, Pullman (ARS)					
Wheat after sweet clover	1944-56	Sweetclover[a]	7.92	4.04	3.81
Wheat after peas, 3rd year after sweetclover	1946-56	Sweetclover[a]	7.92	3.09	2.83
Crop Residue Plots, Pendleton					
Wheat after fallow	1931-56	Pea straw	2.2	3.33	2.81

[a] Topgrowth of sweetclover plowed under was compared with removal as hay crop. Sweetclover was grown every 5 years.

[b] Data reported by Horner, Overson, Barker and Pawson, 1960.

Table 14. Effect of crop rotations and winter cover conditions on erosion losses. Crop rotation plots, 30 percent slope, Soil Conservation Research Station, Pullman, Washington.[d]

Crop rotation and winter cover condition	Period measurements were made	Average annual losses, 1938-56[a]	
		Runoff cm	Erosion t/ha
Wheat-Fallow			
W. wheat after fallow	1938-56	2.81	18.60
Standing wheat stubble	1938-51	0.33	0.08
Average		1.57	9.40
Wheat-Peas			
W. wheat after peas	1938-56	1.88	8.60
Plowed wheat stubble	1938-49	0.30	0.40
Average		0.11	4.60
Wheat-Peas Green Manure			
W. wheat after peas (g.m.)	1938-49	1.42	8.00
Plowed wheat stubble	1938-49	0.20	0.60
Average		0.81	4.40
Wheat-Hubam Clover Green Manure			
W. wheat after clover (g.m.)	1938-49	1.01	6.00
Plowed wheat stubble	1938-49	0.20	0.20
Average		0.61	3.20
Sweetclover Rotations (5-year)			
Sweetclover and grass	1944-49	0.33	0.08
W. wheat after clover (g.m.)	1944-56	1.27	5.80
W. wheat after peas	1946-56	1.57	7.60
Plowed wheat stubble (2 yrs)[b]	1944-49	0.13	0.40
Average		0.68	2.80
Alfalfa Rotation (8-year)			
Alfalfa and grass (3 yrs.)[c]	1944-49	0.33	0.08
W. wheat after alfalfa	1946-56	0.71	2.60
W. wheat after wheat	1944-56	0.76	2.80
W. wheat after peas	1946-56	1.12	4.80
Plowed wheat stubble (2 yrs)[b]	1944-49	0.18	0.60
Average		0.48	1.40

[a] Where measurements were made for periods other than 1938-56, the data were interpolated by comparison with the wheat-fallow and wheat-peas cropping systems. For example, wheat after alfalfa had 0.83 cm of runoff annually during 1946-56, whereas the

Table 14. Continued.

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average annual runoff for wheat after fallow and wheat after peas during the period 1938-56 was 84 percent of the value for 1946-56. Therefore, the interpolated value for wheat after alfalfa for the period 1938-56 is 84 percent of 0.83 or 0.69 cm.

[b] Average annual erosion losses for the two years in the rotation cycle that the cover condition was fall plowed wheat stubble.

[c] Average annual erosion losses for the three years in the rotation cycle that the cover condition was alfalfa and grass.

[d] Data reported by Horner, Overson, Barker and Pawson, 1960.

forage crops grown for silage or conservation, make the maximum use of legumes. Examples are the systems based on alfalfa in Australia, the United States, and Argentina, the British lay farming system based on white clover, and the use of legumes in irrigated farming systems in Australia, South Africa, and other countries (Whyte, Leissner and Trumble, 1953).

It should be noted at this stage that there is a rainfall or precipitation/evaporation limit to the cultivation of legumes in rotation. Below this limit there may be no adapted species but, more important, at the lower-rainfall limits of cultivation in dry-farming systems, the inclusion of a legume in a cereal-fallow will cause a reduction in the yield of the following cereal crops. This is due primarily to excessive removal of moisture from the soil in the growing and rotting of the legume crop and is one of the important factors in the dry farming systems in the Great Plains of the United States and the southern parts of the prairie provinces in Canada. This does not appear to be true in a Mediterranean winter rainfall environment. However, this would seem to be important on rangelands (Whyte, Leissner and Trumble, 1953).

Legumes in erosion control and wildlife

In addition to the multiple contributions of legumes in range improvement, they play also an important role in erosion control and wildlife (Graham, 1941).

The majority of legumes at our disposal are herbaceous plants although some that are important are woody forms, such as *Acacia ligulata*. For obtaining rapid, efficient control of eroding lands, herbaceous cover is often better than woody vegetation. Grasses are usually most effective, but in soil rehabilitation grass-legume mixtures are preferable to grasses alone. Such mixtures provide denser ground cover, tend to prevent weed growth, and produce better forage or hay (Graham, 1941).

Plants for erosion control can be of value to the wildlife manager if those that are selected provide wildlife cover and food throughout the year. The particular importance of legumes to wildlife has been generally recognized by those who are in close touch with practical game management. Intensive work with the bobwhite in the southeast led Stoddart in 1939 to consider legumes so attractive to quail that he stated: "The abundance or scarcity of native leguminous plants over vast areas of coastal "flat woods" little frequented and consequently not sought out by man, could be relied upon as an index to the quail population of the region" (Graham, 1941).

Use of legumes as livestock feed

With improving standards of human nutrition in all countries, combined with the high rate of population growth, there is certain to be increasing demand for food particularly rich in protein, energy, minerals, and vitamins. This demand cannot possibly be met unless animal fodders with high protein content are available and with the preservation of a correct protein/carbohydrate ratio. Until recent times, sufficient concentrated high protein feeds were available to meet the needs of those types of animals demanding a high protein ration. Now, the world supply of these feeds tends to decrease because of diversion to other purposes, especially direct human consumption. Because of the need to conserve the usual protein concentrates for the non-ruminant animals, it is further desirable to meet the protein requirements of ruminants by the use of legumes and their associate species (Whyte, Leissner, and Trumble, 1953).

Legumes are invariably rich in nitrogen and independent of a low status of soil nitrogen; they are regarded as an especially useful and dependable source of protein for animal feeding. Legumes not only contain relatively high percentages of protein at all stages, but the protein itself is of a good quality. They also contain large quantities of calcium and phosphorus which are also important in efficient animal nutrition. They are recognized as providing a superior source of vitamins A and D (Wheeler, 1950).

Legumes may play an important part in filling gaps in the seasonal production of swards. In Great Britian, for example, alfalfa, red and white clover are all used to augment grazing during difficult periods in the summer (Whyte, Leissner and Trumble, 1953).

Legumes in sown pastures

To discuss the place of legumes in sown pastures is to discuss the whole basis of modern grassland management. Research during the past three or four decades has been directed towards discovering the species and strains of legumes which are most suitable for grazing and with root persistence, and how they can be established and maintained in association with the grasses competing with them in a sown mixture (Whyte, Leissner and Trumble, 1953).

Fundamental to the selection of a grazing legume is a knowledge of the conditions under which it is to be grown and grazed. The pastures of some countries such as New Zealand, are kept closely grazed and short;in others, particularly tropical countries, a "pasture" is necessarily much taller (Whyte, Leissner and Trumble, 1953).

The outstanding grazing legume of humid temperate lands is, of course, white clover in one of its several forms, with perhaps alsike clover occupying a very secondary position. Its counterpart in winter rainfall lands, such as South Australia, is subterraneum clover (Whyte, Leissner and Trumble, 1953). The importance of the clover pastures will be discussed in the following part of this paper.

IMPORTANCE OF THE *TRIFOLIUM* SPECIES, IN RANGE IMPROVEMENT

Trifolium species or true clovers have always symbolized soil improvers, good forage and good ranching (Lancaster, 1944). Throughout the world there are approximately 250 species of the genus *Trifolium*, among which only nine are now mostly used in range improvement (Wheeler, 1950). The origin of Trifolium is believed to be Southwestern Asia Minor and Southeastern Europe. Clovers have been subject to many introductions around the world and have recently become the most widely distributed of the legumes.

The true clovers exhibit the basic characteristics of the family Leguminosae. Nevertheless, they have some special properties which are noteworthy.

The clovers are perennial or annual herbs, mostly adapted to cool and moist climates. In regions with hot and dry summers, their growth in the absence of irrigation is confined to the autumn, winter, and spring. They grow best on soils rich in phosphorus, potassium, calcium, and the micronutrients. Temperature and photoperiodism are important in the adaptation of species and varieties, and affect particularly the flower initiation in clover pastures (Aitken, 1955). Generally speaking, most of the *Trifolium* species are long-day plants, although many continue to flower into early fall (Wheeler, 1950).

Most true clovers are trifoliate and carry the flowers in head-like inflorescences. The flowers of some species are self-sterile, requiring cross-pollination. Others are self-fertile but must be tripped or shaken to insure pollination; still others are self-fertile and self-pollinating. The number of seeds per pod varies according to the species from one to eight (Whyte, Leissner and Trumble, 1953).

The nine most important species used in range improvement and which are covered here are subclover (*Trifolium subterraneum*), Crimson clover (*Trifolium incarnatum*), Persian clover (*Trifolium resupinatum*), Rose clover (*Trifolium hirtum*), Red clover (*Trifolium pratense*), Alsike clover (*Trifolium hybridum*), White clover (*Trifolium repens*), Ladino clover (*Trifolium repens* var.) and Strawberry clover (*Trifolium fragiferum*).

Highlights of the Nine Most Important True Clovers

In order to assess the relative values and characteristics of the clover species listed above, each species is dealt with separately in order of its importance in range improvement.

Annual true clovers

Subclover (*Trifolium subterraneum*)

As well as being the outstanding winter-annual pasture legume, subclover, also known as subterraneum clover, is also of major importance in improving permanent pasture, particularly in semi-arid areas. Its efficient seeding habit and seedling vigor enables it to propagate itself year after year in permanent pasture while the annual habit and hard seeds safeguard the species through summer drought (Martin, 1960).

Subclover is native to the Mediterranean basin and the Atlantic regions of Morocco, Iberia, France, and the Southern British Isles (Donald, 1973). Its ability to grow on poor soils and in dry areas was quickly recognized. These qualities coupled with high productivity, ability to establish by surface sowing and a steadily increasing use of superphosphate led to the spread of subclover over wide areas (Williams, Love and Berry, 1957). In Australia, for instance, there are more than 5 million hectares of highly productive subclover pasture in the "well-watered"--380 mm or more annual rainfall--region of South Australia alone (Love, 1959).

A further factor in favor of growing subclover in dry areas is that the seed is a valuable source of protein and carbohydrates for sheep where they have to be carried on dry pasture through the summer. It is also desirable in the high rainfall areas (580-760 mm) as a supplement to other forages because of its superior growth during the autumn and early spring (Martin, G. J., 1960).

Subclover is not very palatable up to the flowering stage and stock neglect it almost entirely. This greatly favors its dominance in heavily grazed pastures, at least in the early phases, when the available nitrogen supply of the soil is still low (Whyte, Leissner and Trumble, 1953).

Description. Subclover is a winter annual legume with prostrate stems up to one foot in length (Wheeler, 1950). The stems (runners) and leaves are covered with short hairs. The leaf has three leaflets, each usually having a whitish crescent across it and frequently having many scattered black flecks over it. The flowers are usually inconspicuous, occurring in groups of four creamy white or pinkish flowers. After flowering, the stalk supporting the head bends toward the ground, and the matured flowers turn backwards. At the tip of the flowering stalk a series of stiff forked bristles develop and reflex in turn. If the head is in contact with the soil at this time the bristles pull the seed into the soil. The seeds are dark purple, smooth, and about 3 mm in diameter. The number of seeds per kg is about 140,000 (Williams, Love and Berry, 1957).

Of the annual clovers, subclover exhibits the best reseeding insurance because of its mechanism for burying seed in the soil. For this reason it is difficult to graze out a stand of subclover. It is a prolific seed producer and a substantial amount of its production is hard seed. These seeds germinate over a period of time to produce a good crop, even though seed germinating with the first rains may die in a succeeding drought or freeze. When subclover makes a lush growth, it reseeds better when grazed than when allowed to grow to the hay stage. This fact, however, is of no concern after two or three seasons of subclover production and a liberal supply of hard seed has been built up in the soil (Williams, Love and Berry, 1957).

Adaptation.

Climatic limits. The principle indices of survival and success of any self-regenerating annual herbage plant are the number of seeds produced and the persistence of those seeds until favorable conditions occur for seedling establishment. In these terms, subclover is adapted to climates having relatively warm, moist winters and dry summers with 380-760 mm annual rainfall and up to an elevation of

1,000 m (Williams, Love and Berry, 1957). It is not tolerant of poor drainage. Well established seedlings can survive temperatures as low as -12°C (Wheeler, 1950). The effect of temperature and photoperiodism on flower initiation in early and later flowering varieties has been investigated in Australia and led to the determination of the geographical limits of the use of subclover (Aitken, 1955). The temperature has also an effect on seed germination, seed production and uptake of some nutrient elements, particularly sulphur (McKell and Wilson, 1963).

Edaphic limits. The most notable of edaphic limitations is the influence of pH on the distribution of subclover. This species thrives on acid or neutral soils, generally of lighter texture, and has succeeded mainly at pH 5-7 (Donald, 1973). In most areas where it is often used, its success has been dependent upon the use of superphosphate, nitrogen, and potassium, less commonly in conjunction with such trace elements as sulphur, molybdenum, copper, and zinc (Donald and Williams, 1954).

Establishing and maintaining of a stand.

Sowing the seed. Subclover should always be sown in mixtures with adapted, companionable grasses when it is to be used for forage, and alone when it is to be assigned primarily for seed production (Wheeler, 1950). The perennial grasses sown with subclover increase total production, lengthen the green feed period, and stabilize year-to-year forage production (Williams, Love and Berry, 1957). Growers often establish subclover on old grass sod by broadcasting the seed in the fall without seedbed preparation. A better method of establishing subclover without seedbed preparation is to scatter threshed subclover straw over the land and trample it into the soil with livestock (Le Houerou, 1975).

In California, Sudangrass has been used successfully as a cleanup crop prior to planting subclover and other annual clovers. Since Sudangrass is planted late in the spring, volunteer vegetation must be turned under prior to seed formation. Sudangrass exhausts soil moisture in the early summer, thereby preventing summer weeds from making any headway, and furnishes nutritious summer feed. Clover seed should be drilled into the Sudan stubble without seedbed preparation.

Controlled burning of tall dense brush provides a desirable seedbed for clovers (Williams, Love and Berry, 1957).

Time of sowing. Subclover is naturally adapted to early fall sowing. If sown later in the fall, the young plants may suffer winter injury due to soil heaving. They are also more susceptible to damage by slugs. Spring sowing in April, May or June on well-prepared seedbeds is often practiced where soils heave badly by winter frosts (Wheeler, 1950).

Rate of sowing. Subclover is usually sown alone for seed production at rates varying from 6 to 10 kg per ha. When the crop is to be utilized as forage, the recommended rate is not less than 3 kg of seed per ha in combination with grasses (Wheeler, 1950).

Inoculation. Inoculation of the clovers with nitrogen-fixing bacteria is good insurance for stand establishment. Difficulties in subclover establishment due to poor nodulation have been recognized on several soils around the world for many years. However, only during the past ten years following the isolation and use of effective *Rhizobium* strains has any significant progress been made in understanding and overcoming them.

Nodulation problems were recognized as being of two types: (1) On the strongly acid soils ($pH<5.2$) poor nodulation of subclover and other clovers with very high seedling mortality was invariably obtained in the absence of lime. On many areas, broadcast applications of lime at 2 tons per hectare before sowing overcame this problem. Also, it has been found that responses equal to those obtained with heavy dressings of lime can be obtained by the application of molybdenum together with only 200 kg of lime per hectare at seeding (Anderson and Moye, 1952). (2) Poor nodulation resulting in patchy growth of true clovers was also frequently observed during the first year or so after sowing on the less acid soils ($pH>5.2$). With annual applications of superphosphate, growth of clovers on most of these areas steadily improved until, by the end of the second or third season, a satisfactory stand was obtained (Paton, 1960).

In certain other soils of pH 6-7, failure of inoculation has been shown to be associated with microbiological antagonism in the rhizosphere of the seedlings resulting in severe limitation of the spread of nodule bacteria from the inoculum of the seed. A number of ameliorative measures have been tried and one of the most effective was an increase in the numbers of bacteria in the inoculum. Subclover seed pelleted with bentonite and organic material overcame this problem (Table 15) (Bergersen, Brockwell and Thompson, 1958).

Table 15. The effect of pelleting on rhizosphere numbers of *Rhizobium trifolii* for 3-week-old seedlings of subterraneum clover near Armidale, N.S.W., Australia.[a]

	Numbers of *R. trifolii* in the first cm of main root of 4 plants		
	Site 1	Site 2	Site 3
Unpelleted seed	0	0	10
	0	1	0
	>1,000	100	100
	0	0	0
Pelleted seed (benthonite-dried blood)	1	>1,000	>1,000
	>1,000	>1,000	>1,000
	>1,000	>1,000	>1,000
	>1,000	>1,000	1

[a] Data reported by Bergenson, Brockwell and Thompson, 1968.

In addition, consistent failure of establishment of oversown subclover or clovers in general (even when seed is inoculated and all fertilizers needed are supplied) is a serious problem in some ranges. Evidence gathered by Beggs in 1964 suggests that clover growth is severely inhibited by some soil organisms and formalin has been the most efficient material in overcoming the problem.

Seed treatment with a fungicide may also be profitable where seedling diseases are a problem in obtaining stands. However, many fungicides, particularly those containing mercury, destroy legume bacteria when both are applied to the seed. When fungicide-treated seeds are used, inoculation should be the last operation performed before planting, and the interval between inoculation and planting should be as short as possible (Williams, Love and Berry, 1957).

Fertilization. Soil fertility is an important factor in obtaining high production from the clovers. The two fertilizer elements that improve range clovers growth most frequently are phosphorus and sulphur. Single superphosphate is a good remedy for the deficiency of these two elements since it contains substantial amounts of both (18-21 percent P_2O_5 and 10-20 percent S). The benefits from phosphate fertilization of the clovers are illustrated by experiments performed on a red claypan soil near Lincoln, Placer County, California. Inoculated subclover, rose clover (*T. hirtum*), and crimson clover (*T. incarnatum*) were planted just prior to fall rains. In three fields single superphosphate was applied at the rate of 150-200 kg per hectare and in another treble superphosphate was applied at the rate of 150 kg per hectare. On the area improved in this manner, the carrying capacity was tripled in the following three-year test period. The increase in forage is shown in Figure 8. Protein contained in the feed was increased by two times in field 3 and up to nine times in field 4. This resulted from both the greater amount of forage produced and the increase in protein percentage from 9.0 percent unfertilized to 13.1 percent fertilized. The phosphorus content of the feed was also improved (Williams, Love and Conrad, 1956).

In some podzolic soils of Australia, the introduction of subterraneum clover, together with superphosphate, initiates a sere which finally results in a complete change in the composition of the sward and also the chemical composition of the forage (Table 16). Figure 9 shows the yield and botanical composition by weight of the pasture from open quadrats (i.e., unprotected from grazing). They are grouped according to the phosphate status of the soil. As the fertility level is raised the native perennial grasses and non-graminaceous species disappear. It is of interest that the several naturally-established Trifolium species found in the native pastures also succumb to the competition of Trifolium subterraneum, almost certainly a consequence of shading since all these clovers would respond vigorously to superphosphate in the absence of competition. The subterraneum clover achieves strong dominance, associated with a fourfold increase in the yield of dry matter (Donald and Williams, 1954).

Thus an application of superphosphate (16 percent) at 200 to 300 kg per hectare, or gypsum and treble phosphate (45 percent) at

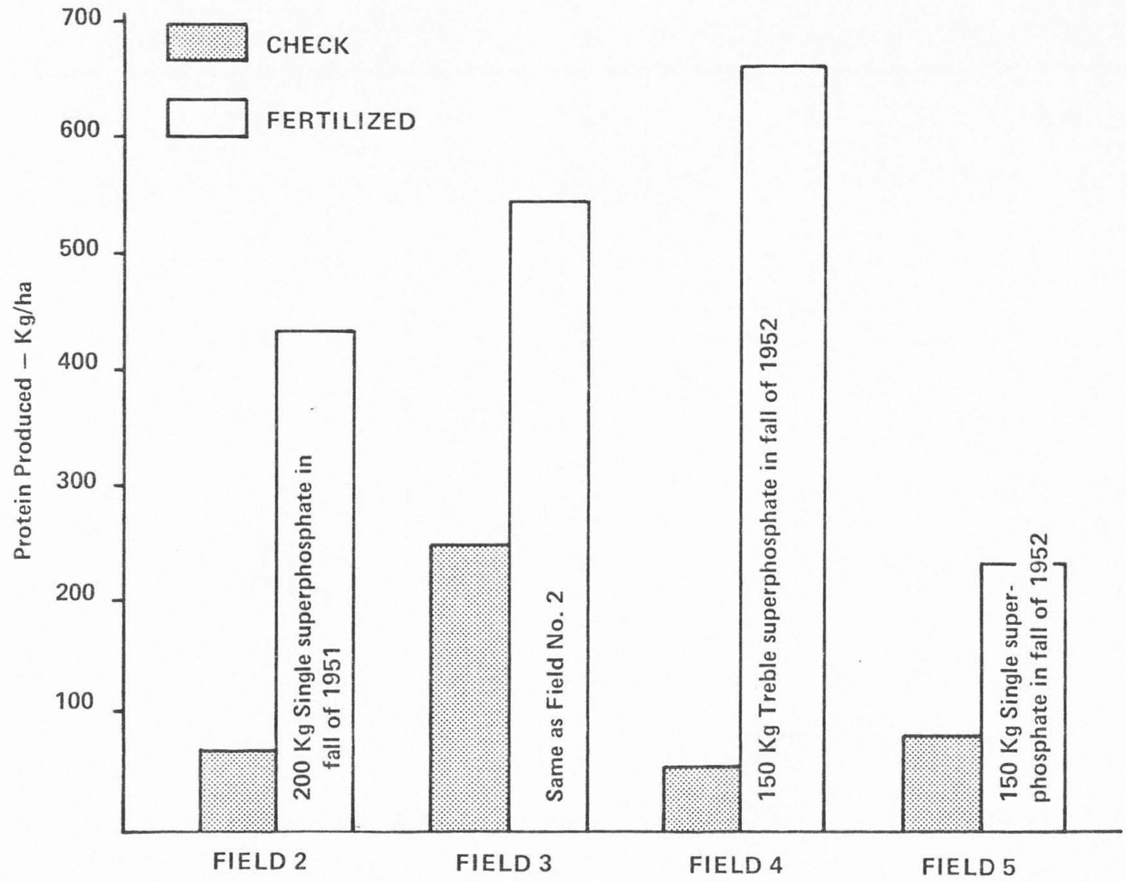

Figure 8. The effect of phosphorus fertilization on the production of protein by range seeded with annual clovers (harvested May 22-27, 1953). Data reported by Williams, Love and Conrad, 1956)

Table 16. The effect of phosphorus fertilization on the composition (dry basis) of forage on range seeded with annual clovers (May 22-27, 1953 harvest). Average of all fields (%).[a]

Forage	Treatment	Protein	Fiber	Fat	Ash	N free extract	Phosphorus	Calcium
Clovers	Check	12.1	30.6	1.7	5.5	49.6	.098	1.37
	Fertilized	14.3	30.8	1.7	4.9	48.5	.144	1.37
Resident annuals	Check	6.6	30.0	1.9	6.9	54.6	.103	1.56
	Fertilized	8.2	29.2	1.8	7.1	53.7	.120	1.58
Total feed	Check	9.0	30.6	1.8	6.2	52.5	.099	1.46
	Fertilized	13.1	30.6	1.6	5.3	49.4	.136	1.40

[a] Source: Williams, Love and Conrad, 1956.

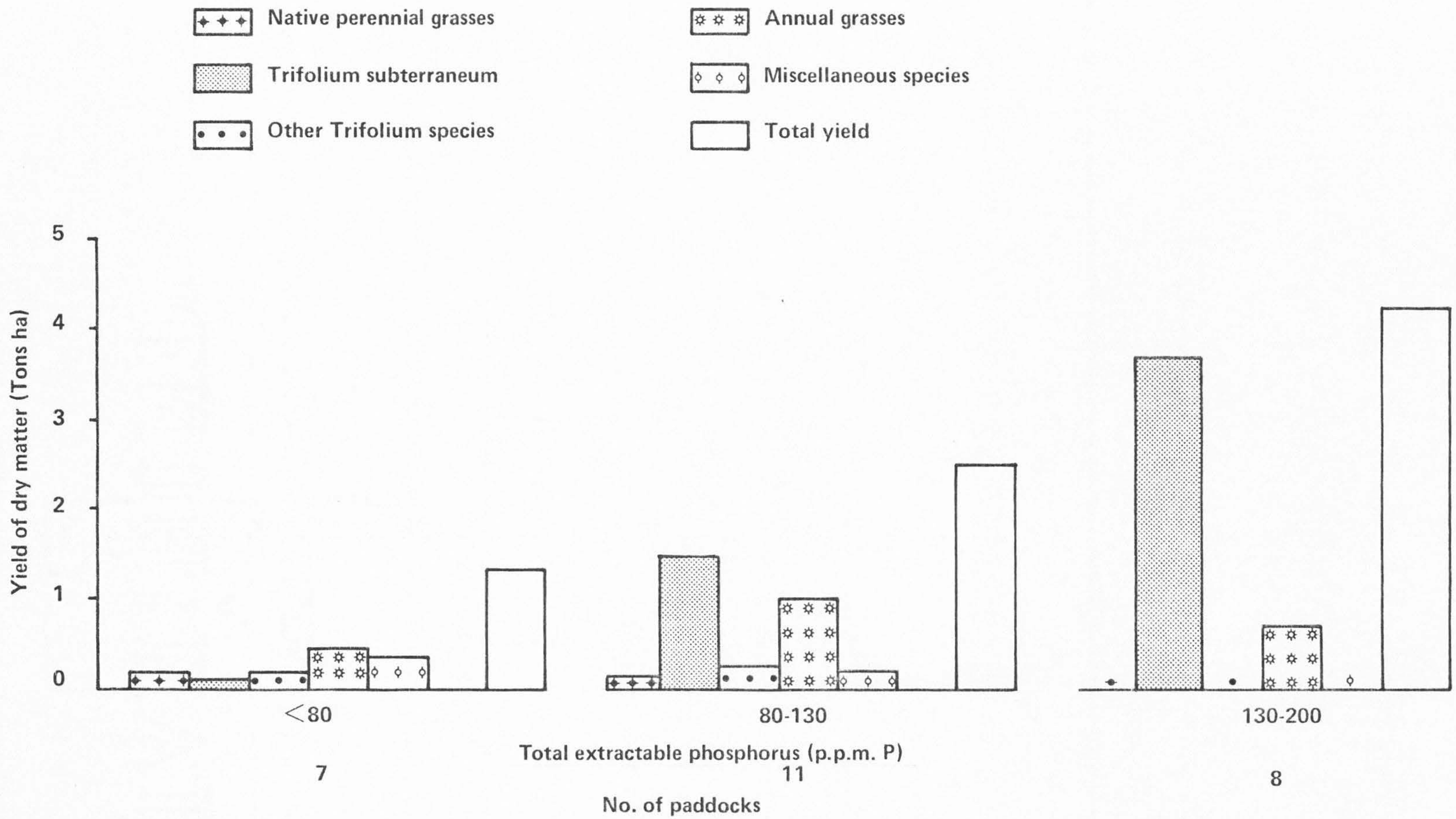

Figure 9. The relationship of pasture yield and botanical composition to the phosphorus status of the soil. Data reported by Donald and Williams, 1954.

100 to 150 kg per hectare at time of seeding, will aid the establishment of range clovers in general and of subterraneum clover in particular (Wheeler, 1950).

Range clovers should be refertilized every two or three years. Local experience will best determine the amount of fertilizer necessary to maintain a productive stand of clover (Williams, Love and Berry, 1957).

Utilizations. In addition to their major contribution in increasing the soil fertility, particularly in terms of nitrogen and organic matter, clovers and especially subclover have many other important uses in improving ranges.

Subclover is relished by all kinds of livestock. As an annual reseeding species it can provide the animals with an abundance of nutritious feed during the spring season, and good dry feed during the summer and fall. Its mixture with perennial grasses on the better sites will lengthen the season of use by providing green feed earlier in the fall and later in the spring. Such dryland pastures make an ideal supplement to unimproved range. Additional fall and winter green feed can be made available on the native range by the application of fertilizer in the fall using nitrogen alone or in combination with phosphorus or sulphur (or both) depending on the particular soil.

Subclover, as well as the other annual true clovers, grows successfully when mixed with grain crops where seasonal moisture is adequate. These clovers will not ordinarily grow as robustly when competing with cereals as when sown alone. But they provide a good aftermath feed to supplement the cereal stubble and they will volunteer in subsequent years, furnishing nutritious feed in the seasons when cereal is not sown as well as adding nitrogen to the soil to benefit subsequent grain crops. The clovers should be planted after the cereal, otherwise they will be buried too deep (Williams, Love and Berry, 1957).

Subclover in grazing management. Timely grazing is essential to insure permanent stands of subclover and other clovers. Newly seeded areas should be grazed as soon as the weeds and annual grasses are of foragable height. By that time the cotyledons (seed leaves) of the clovers will have dropped off, and true leaflets will have formed. The plants will be 5 to 13 cm high. The field should be grazed to a uniform height of about 8 cm for a period no longer than a month. Care should be taken to prevent trampling damage if the soil is wet.

It is almost impossible to harm a new seeding in the first spring by "over-grazing." The important thing is to remove the stock well before the last spring rains to allow the seeded species to mature a seed crop. The field should be grazed again before the fall rains to trample the seed into the ground and so thicken the stand.

A weed-free seeding in the ash of 2 brush burns becomes better established if stock is kept off the first season until the seeds begin to shatter. Annual legumes do well in burned areas because there is usually no competition from resident annuals. Where there is competition from annual grasses or sprouting brush, an early grazing is helpful (Williams, Love and Berry, 1957).

Clover pastures require a balanced grazing program. This plan must be based on individual ranch conditions, kind and number of animals, their distribution over the area, and practical necessities such as cross-fencing and stockwatering facilities.

A grazing rotation plan has been found practical and effective in improving the range. Such a grazing cycle should serve to keep the proper balance of forage species in all divided fields.

The use of a mixture of annual true clovers of varying growth habit allows a much greater latitude of adjustment of livestock use than is otherwise possible. Hence the application of a rotation plan can be quite flexible for mixtures (Williams, Love and Berry, 1957).

Subclover controls range weeds. The greater part of experimental work on the control of weeds by sown pasture species has been done in Australia. It is convenient, indeed, that many pasture weeds can be controlled by the sown sward species themselves. This applies particularly to areas suitable for the growth of subclover and perennial grasses (Michael, 1973).

Moore and Cashmore in 1942 demonstrated unequivocally that St. John's wort could be controlled by subclover aided by superphosphate. Results of a harvest taken in the fourth summer following sowing of six pasture mixtures are given in Table 17 (Michael, 1973).

Subterraneum clover has also been used with success in the suppression of skeleton weed (Chondrilla juncea) which although a very useful plant in pastures of certain areas such as New South Wales in Australia, causes much trouble in cereal crops. Control is associated with shading and raising soil nitrogen levels (Moore, 1973).

Table 17. Control of St. John's wort by subterraneum clover.[a]

Pasture Species	Yield of St. John's wort kg per hectare in fourth season after sowing pastures
Perennial ryegrass-cocksfoot-white clover	590
Perennial ryegrass-cocksfoot-subterraneum clover	1
Phalaris tuberosa-white clover	568
Phalaris tuberosa-subterraneum clover	4
Wimmera ryegrass-white clover	848
Wimmera ryegrass-subterraneum clover	98

[a] Original source: Moore and Cashmore 1942.

Varieties of subclover. Subclover is quite variable in plant types. A large number of different strains has been isolated and recognized. These are grouped into three types: early, mid-season, and late. The early strains are relatively low in production and are useful in areas of low rainfall where later maturing strains cannot persist. In general the later strains are the highest forage and seed yielders and require the most favorable growing conditions, particularly length of the rainfall season, kind of soil and amount of moisture. Table 18 shows the conditions required by some sub-clover cultivars (Maignan and Ibnattya, 1975).

No fewer than eleven "naturally occurring" biotypes of subclover are currently in use as cultivars, and it is of interest to consider the reasons for which each of these was commercialized in Australia (Table 19) (Donald, 1973).

Forage and seed production of subclover. Subclover grown in favorable conditions produces a large amount of forage and seeds. Nevertheless, these quantities differ from one cultivar to another. Table 20 shows some experimental results obtained in Portugal from some Australian cultivars of subclover (Crespo, 1970).

Diseases and insects. Stem rot, when present, causes rapid dying of infected plants and is most active on subclover in late winter and early spring.

The principal insect pests of subclover are the common garden slug and the eleven-spotted cucumber beetle. Slugs are generally most destructive to the young seedlings of tall plantings. The eleven-spooted cucumber beetle is destructive to the seedlings of

Table 18. Precipitation characteristics and kind of soil required by some subclover cultivars.[a]

Cultivars	Length of rainfall season required (months)	Kind of soil	Minimum amount of rainfall required (mm)
Geraldton	4	All kinds of soil	229
Seaton Park	6	All kinds of soil	305
Dwalganup	5	Moderately calcareous	311
Yarloop	6	Moist	432
Woogenellup	6	Light	458
Clare	6	--	407

[a] Reported by Maignan and Ibnattya, 1975. Original sources: Wesfarmes--Guide to western Australia grown agricultural pastures seeds. 22 p. 1968 and CSIRO--Australian herbage plant register. Division of Plant Industry CSIRO, Canberra, A.C.T. 225 p. 1967.

Table 19. The cultivars of subterraneum clover in commercial use in 1969 (Australia) (Donald, 1973).

Cultivar	Locality and date first named	Date commercialized or registered	Maturity	Seed production mean of 1966-7 and 1967-8 (tons)	Reasons for commercialization
Mt Barker	Mt Barker S.A. 1889	1906	Mid-season	1127	New species, fitted to Mederranean-type environment
Dwalganup	Boyup Brook W.A. 1900	1929	Very early	394	Very early flowering. Successful in lower rainfall areas.
Tallarook	Tallarook Vic. 1928	1935	Late	17	Dense, leafy; good late spring grotwh in late districts.
Bacchus Marsh	Myrniong Vic. Early 1930's	1937	Early mid-season	144	Suitable for areas marginally dry for Mt Barker
Yarloop	Yarloop W.A. 1937	1939	Early	444	Good winter growth on water-logged soils.
Clare	Clare S.A. 1941	1950	Early mid-season	62	Good early winter growth. Ability to compete with weeds (long petioles).
Geraldton	Moonyoonka W.A. 1950	1958	Very early	2103	Matures seed rapidly. Successful in very dry spring conditions.

Table 19. Continued.

Cultivar	Locality and date first named	Date commercialized or registered	Maturity	Seed production mean of 1966-7 and 1967-8 (tons)	Reasons for commercialization[a]
Woogenellup	Manjimup W.A. 1951	1958	Early mid-season	3013	Highly competitive against Mt. Barker. Much better persistence than Bacchus Marsh
Dinninup	Boyup Brook W.A. 1957	1961	Early	83	Replacement for Yarloop (highly oestrogenic). Used where season too short for Woogenellup. Well adapted gravelly and sandy soils.
Daliak	York W.A. 1929	1967	Early	61	Low oestrogenicity. Will replace Dwalganup (highly oestrogenic) under heavy grazing.
Seaton Park	Adelaide S.A. 1932	1967	Early	52	Low oestrogenecity. Good competitor. Will replace Yarloop (highly oestrogenic)
Howard	Bred, CSIRO Canberra	1964	Early mid-season	86	Resistant to clover stunt virus
Uniwager	Bred, Univ. of W.A.	1966	Early	13	Very low oestrogenic activity.

[a] The characteristics listed in this column do not include those which have become known subsequently to commercialization, e.g., a degree of tolerance of high pH by cv. Clare, or the medium to low oestrogencity of cv. Woogenellup.

Table 20. Production of forage and seeds obtained by some Australian cultivars of subterraneum clover.[a]

Cultivars	Environmental data of the sites of collections			Agronomic data				
	Rainfall (mm)	Soil type	Altitude (m)	Flowering time (days later than Dwalganup)	Dry matter yields (tons/ha)	Leaf/stem ratio	Seed yields (kg/ha)	Weight (g) of 1,000 seeds
Dwalganup	500-600	Light, grey (shist)	155-165	0	3.5	0.4	289	6.1
Geraldton	600-700	Heavy-grey brown (shist)	350-360	3	3.6	0.5	1120	5.5
Yarloop	500-600	Grey (shist)	250-260	11	6.7	0.5	219	12.0
Woogenellup	700-800	Heavy, brown, wet	300-310	21	6.6	0.8	335	8.9
Bacchus Marsh	600-700	Loam, red, acid	340-350	22	6.9	1.0	361	6.4
Clare	500-600	Clay loam, red (limestone)	220-230	29	6.9	0.8	918	7.9
Mount Barker	600-700	Gray brown (shist)	340-350	32	8.3	1.1	761	7.4
Tallarook	600-700	Clay loam, red (limestone)		36	5.9	1.1	481	5.6

[a] Data reported by Crespo, 1970.

spring plantings. No effective control method is known, but a timely application of DDT dust might control them (Wheeler, 1950).

Crimson clover (<u>Trifolium incarnatum</u>)

Crimson clover is the most important winter annual legume on rangeland. This crop can be grown by using seed of adapted varieties for each specific site, by using good cultural methods, and by fertilizing the soil. Besides being an excellent pasture plant and furnishing plenty of hay, it protects the soil during fall, winter, and spring, prevents soil washing, and provides green manure for soil improvement. This clover has also the distinct advantage of producing large quantities of seed that can be easily harvested and sown without the use of expensive machinery (Hollowell, 1947).

Crimson clover is a native of Europe and is widely grown in the Mediterranean area, central Europe, and other countries (Whyte, Leissner and Trumble, 1958).

<u>Description</u>. Crimson clover is an upright plant 15 to 75 cm high and has cylindrical heads about 50 cm long of bright crimson flowers. The stems and leaves are covered with soft hairs. The leaflets are usually unmarked although they occasionally have small dark-brown blotches next to the midvein. The seed is yellow and shiny (Wheeler, 1950). It germinates immediately after ripening, as soon as adequate moisture is present. This is an undesirable characteristic, as germination will occur after light rains and the seedlings may die when the soil dries again. Breeding has been carried out in the United States to obtain varieties which will

produce volunteer stands (Whyte, Leissner and Trumble, 1953). There are 300,000 seeds per kg (Williams, Love and Berry, 1957).

Adaptation.

Climatic limits. Crimson clover does well in cool, humid weather, and is tolerant of winter conditions where the temperature does not become severe or too changeable. It performs well on 380 or more mm of annual rainfall at elevations under 1,000 m. It may be planted from mid-summer to late-fall (Hollowell, 1947).

Edaphic limits. Crimson clover thrives on both sandy and clay soils and is tolerant of ordinary soil acidity. On very poor soils stands are difficult to obtain and the growth is stunted. The use of phosphate and potash fertilizers and manure on such soils will help to obtain good stands (Wheeler, 1950).

Establishing and maintaining a stand.

Seed sowing. Crimson clover is sown from the middle of July until November, depending upon the location and the use for which it is grown. If fall and winter grazing is desired, clover must be planted sufficiently early for plants to develop before the advent of cold weather. Where temperatures are low and clover is subjected to soil heaving, plants must be well established or they may exhibit winterkill. Seeding crimson clover either immediately preceding or soon after a heavy rain increases the chances of a successful stand; adequate soil moisture is essential (Heath, Metcalfe and Barnes, 1973).

The recommended seeding rate is 22-34 kg/ha, the higher rate being desirable. The amount of seed to use depends on the condition of the seedbed, use to be made of the clover sward, price of seed, and companion crops planted with the clover (Knight, 1967).

Crimson clover can be grown successfully with other crops such as winter grains, annual ryegrass, and other winter annual legumes (Hollowell, 1947).

Inoculation. Crimson clover seed should be inoculated when planted on soil where clover is not grown the previous year. When grown in association with perennial grass and if plants are thoroughly nodulated the first year, it usually is not necessary to inoculate in succeeding years (Heath, Metcalfe and Barnes, 1973).

Fertilization. Good stands and growth cannot be expected on very poor soils. Soil conditions can be improved by adding phosphate and potash fertilizers and manure or by turning under such crops as cowpeas (Vigna sinensis), soybeans (Glycine max), or lespedeza (Lespedeza spp.). In many soils of low fertility the use of a complete fertilizer will encourage early seedling growth and establishment. On fertile soils crimson clover may be successfully grown without fertilizer, but on most soils applications of 200 to 400 kg per hectare of phosphate and 50 to 100 kg of potash pay in obtaining good stands and vigorous growth (Hollowell, 1947). Boron may be needed if a seed crop is to be harvested (Adams and Stelly, 1958).

Companion crops. Rye (Lolium spp.), vetch (Vicia spp.), and fall-sown grain crops are often seeded with crimson clover. Such crops are seeded at half to a third the normal rate, and the crimson clover is seeded at half to two-thirds the normal rate. Seeding is done at the same time but, as a greater depth is required for most of the seed of the companion crops, two seeding operations are necessary (Wheeler, 1950).

Farmers often use a mixture of 5 kg of red clover and 10 kg of crimson clover per hectare with excellent results. The first growth of the mixture may be grazed or harvested for hay or for crimson clover seed, while the second crop is wholly red clover (Hollowell, 1947).

Utilization and benefits. Crimson clover is regarded as one of the most important winter annual legumes for many areas around the world. It will grow under a wide range of climatic and soil conditions, has many uses (pasture, hay, green manure, and silage), produces large yields of easily-harvested seed, thrives in association with other crops and fits into many crop sequences.

Pasture. Crimson clover grows rapidly in fall and spring and furnishes an abundance of grazing forage. If planted early and good fall growth is made, the clover may also be grazed during the fall and winter months. Such practice has been successfully followed in many areas in the United States where crimson clover is providing winter pasture. Crimson clover combined with small grains of ryegrass has been most widely used for winter grazing. It makes little growth during cold periods in winter. Under such conditions to prevent close grazing, it is necessary to remove the animals or shift them to other fields that have not been grazed (Wheeler, 1950).

Animals grazing on crimson clover seldom bloat; however, it is advisable not to turn them into clover fields for the first time when they are hungry. Bloat is less likely to occur on a mixture of clover and grass or grain than when the clover alone is grazed. As crimson clover reaches maturity the hairs of the heads and stems become hard and tough. When it is grazed continuousaly or when it is fed as hay at this stage large masses of the hairs are liable to form into hair balls in stomachs of horses and mules, occasionally with fatal results. If small quantities of other feeds, particularly roughages, are fed along with the clover, the formation of these balls will be reduced. Cattle, sheep, and swine do not seem to be affected (Hollowell, 1947).

Green manure. Crimson clover is an ideal green manure crop. For best results it should be plowed under 2 to 3 weeks before the succeeding crop is planted. This gives enough time for decomposition, which is rapid unless the crop is ripe when turned under. Occasionally strips are plowed in which row crops are to be planted, allowing the clover between the plowed strips to mature. Seed may be harvested by hand from the clover between the row crops, and the remaining clover straw allowed to mat and serve as a mulch, or the entire plant may be permitted to form a mulch (Wheeler, 1950).

Hay. Crimson clover makes excellent hay when cut at the early-bloom stage, although the yield may be slightly reduced. For best yields it should be harvested in full bloom. The hay is easily cured either in the swath or in the windrow. Fewer leaves are lost and less bleaching occurs in windrowed hay. Although yields as high as 5 tons per hectare are not uncommon on fertile soil, 3 to 4 tons is the usual harvest (Hollowell, 1947). A good stand of crimson clover will yield from 2 to 4 tons hay/ha depending upon growth conditions and the intensity of grazing. Crimson clover is high in nutritive value in the prebloom stage (Heath, Metcalfe and Barnes, 1973).

Silage. Crimson clover may be made into silage by the same methods as are used for other legumes and grasses. In orchards it is often allowed to mature, after which it is disked into the soil (Wheeler, 1950).

Seed production. With good stands and pollination, crimson clover seed set may range from 500 to 1,000 kg/ha (Villax, 1963). Seed losses during combining decrease the average harvested yield to approximately 250 kg (Heath, Metcalfe and Barnes, 1973). Tripping of florets is important in setting seed. Placing colonies of honeybees in or adjacent to seed fields is highly recommended (Hollowell, 1947).

Varieties of crimson clover. The seed of common crimson clover has the undesirable characteristic of immediate germination. This may occur at any time throughout the summer after seed is mature, or after sowing in the fall (Whyte, Leissner and Trumble, 1953).

Recognizing the weakness of common crimson clover, breeding has been carried out in the United States to obtain varieties which will produce volunteer stands. The following are now avilable (Whyte, Leissner and Trumble, 1953):

Dixie is a mixture of equal parts of three strains selected for resistance to early germination in spring when grown as a winter annual. It has a high percentage of hard seeds and produces volunteer stands successfully in the autumn, when moisture conditions are more reliable. This variety is widely grown in the southeastern United States.

Auburn, a variety selected from a volunteer stand in Auburn, Alabama, also produces good volunteer stands when followed by crops of grain sorghum, Sudangrass, or permanent pastures.

Autauga, similar to Dixie, but slightly earlier in maturity.

Talladega, slightly later than the others.

Diseases and pests. Soothy blotch is a foliage disease that infects crimson clover. Symptoms are dark spots on the leaves which cause leaf loss during blooming and lower the value of the forage. Slime mold has also been observed on seedling crimson clover, but apparently has not caused serious damage. Crimson clover is also susceptible to the pea aphid and is considerably damaged under a heavy infestation (Williams, Love and Berry, 1957).

Persion clover (*Trifolium resupinatum*)

Persian clover is a winter annual legume native to southern Asia Minor and the Mediterranean countries (Villax, 1973). It is adapted to wet situations on rendzina-type soils in southeastern South Australia, and is there called annual strawberry or birds-eye clover. In the United States it is adapted to the southern part where it is used primarily for pasture and hay (Whyte, Leissner and Trumble, 1953).

It produces forage in late winter and early spring when grasses are dormant. It is nutritious and liked by all kinds of livestock (Wheeler, 1950).

Persian clover can be sown alone or associated with some grasses such as Lolium rigidium and Lolium multiflorum (Maignan, 1973). When it is grown with grasses, Persian clover improves the quality and quantity of the grasses by furnishing nitrogen. Once established in properly-managed plantings, it reseeds itself year after year (USDA, 1960).

In some areas, Persian clover is used for green manure or for silage as well as for pasture, hay, and soil improvement (Heath, Metcalfe and Barnes, 1973).

Description. Persian clover is a true winter annual. The seed germinates in the fall and the plants grow throughout the winter months in the form of a low rosette. With the advent of spring rapid growth occurs and many slender upright flower stems develop. Seed is produced in late spring or early summer, after which the plants die. When grazed heavily or when the stand is thin, the stems become decumbent (Wheeler, 1950). There are 1,300,000 seeds per kg.

Adaptation.

Climatic limits. Persian clover is well adapted to Mediterranean climate. It requires enough rainfall in winter and is strongly resistant to cold conditions, to poor drainage, and to moderate dryness (Maignan, 1973).

Edaphic limits. Heavy, moist soils in low-lying areas are best suited for Persian clover. It does not do well in upland sandy soils (Wheeler, 1950).

Establishing a stand.

Preparing the seedbed. Persian clover usually is seeded on a grass turf. Successful stands have been obtained from sowing on cultivated soil. One of the main reasons for failure is the occurrence of hot dry weather before the seedling plants become established. A firm seedbed is essential. The seed is usually broadcast and may be lightly covered. When the clover is sown on a grass turf, the grass should be either closely grazed or clipped before the sowing is done (USDA, 1960).

Sowing the seed. Persian clover must be sown in the early fall to produce good yields the following spring. If conditions are favorable for germination and stand establishment, 15 kg of seed per hectare will produce a good stand (Maignan, 1973).

Inoculation. For productive stands, Persian clover seed must be inoculated. If the weather remains hot and dry for more than a few days after the field has been seeded, more inoculating culture should be applied, seeding should be delayed until rainy weather occurs; then a broadcast application of culture mixed with sand should be made.

Volunteer stands may be inoculated the second year even though the first year's stand was well inoculated. This practice is most common when the clover is used as a green-manure crop than when it is seeded with grasses.

For seeding green-manure crops, one should use inoculated seed every year.

For seeding clover on grass turf, one should use inoculated seed the first two years. After the second year, further inoculation on grass turf is unnecessary (USDA, 1960).

Liming and fertilizing. Persian clover can be grown successfully on medium to slightly acid soils. On strongly acid soils 1 to 2 tons per acre of limestone is recommended. All fertilizer application should be made in the fall shortly before sowing, or in the fall of following years just before the volunteer seed is germinating. The fertilizers may be either drilled or broadcast (Wheeler, 1950).

For successful growth, Persian clover needs mineral fertilizers. Recommendations for phosphate application usually are in the range of 200 to 500 kg of superphosphate at seeding time. This is followed by supplemental applications of 100 to 300 kg per hectare every year or two. Annual application of 100 to 200 kg of muriate of potash per hectare may be necessary (USDA, 1960).

Utilization. In addition to its contribution in raising the soil fertility in terms of nitrogen and organic matter, Persian clover has many other uses which improve the range and livestock production.

Pasture. Persian clover is an excellent grazing plant. It produces a high quality, nutritious, protein feed from late winter to late spring. It extends the grazing season and stimulates its companion summer grasses. Persian clover pastures have a high carrying capacity during spring months from March to early May.

Hay. Persian clover hay, if properly cured, is nutritious and is well liked by livestock. Stands of Persian clover generally yield 1 to 2 tons of hay per hectare. The clover should be cut for hay when it is between one-quarter bloom and full bloom. The highest quality hay is from plants cut at the one-quarter bloom stage of growth. When the crop is cut at this stage, the regrowth has time to set seed.

The largest yield of hay is from plants cut in the full-bloom stage. When the crop is cut at full bloom, the regrowth will not produce seed.

Persian clover has a high moisture content, but the stems are fine and the plants are fairly easy to cure (USDA, 1960).

Silage. Silage from Persian clover is an excellent feed for beef and dairy cattle. For maximum yields, clover should be ensiled when it is slightly past full-bloom stage (Wheeler, 1950).

Green manure. Persian clover green-manure crops yield as much as 30,000 kg of green material per hectare. The green-manure crop can be grazed lightly early in the season, or a seed crop can be harvested before turning under the green manure.

The soil-improving value of Persian clover is high and is not materially reduced if only the straw is turned under (USDA, 1960).

Seed production. Persian clover is a prolific seed producer. Under ideal conditions, yields of 700 kg of seed per hectare are possible (Villax, 1963).

The same crop can be used for both grazing and seed production. To use it for both purposes, the clover should be grazed closely until about 4 weeks before the clover normally blooms. Then the animals should be removed and the clover left to bloom and form seed heads (Wheeler, 1950).

Shattering. Persian clover seed shatters easily. This sometimes makes the seed crop difficult to save. To reduce losses from shattering, harvest of the seed crop may be necessary as soon as it is ready (USDA, 1960).

Rose clover (Trifolium hirtum)

Rose clover is an annual winter legume, native to Turkey. It has proved to be the most widely adapted legume for range use in Mediterranean regions (Love and Summer, 1952).

In central Europe, rose clover is described as growing "in dry, sterile fields, on slopes, on sandy steppes, on roadsides, and in waste places" (Love, Dorman and Sumner, 1952).

Rose clover plays an important role in range improvement from the standpoint of its adaptation and usefulness. It will grow and thrive on soils that will not support good growth of subclover. It has the advantage of self-seeding. It increases the soil fertility and prepares the way for other legumes and grasses. Rose clover will crowd out undesirable annuals and if properly handled it will also reduce the population of summer weeds (Love, 1951).

Description. Rose clover, a freely-branching plant is 7.5 to 60 cm tall. The branches are covered with short, stiff hairs. Each leaf has three leaflets. The flower heads are rose colored and the seeds are yellow. The number of seeds per kg is 300,000 (USDA, 1976).

Adaptation.

Climatic limits. Rose clover is widely adapted to Mediterranean climate below 1,100 m elevation except in the areas receiving less than 250 mm of rain.

Edaphic limits. It is adapted to a wide range of soil texture and soil depth. It does well on strongly acid to moderately alkaline soil conditions but does poorly on waterlogged soils.

Establishment on annual type ranges.

Seedbed preparation. Rose clover establishment is improved with some type of seedbed preparation. Several methods have been successfully used.

The conventional system of plowing and disking in the spring prior to establishment and before native annual species set seed is highly successful (USDA, 1976).

In order to obtain good rose clover stands, the seedbed must be firm, the seed covered with light mulch of soil and organic matter, the young plants having a ready source of phosphate, and the nitrogen-fixing bacteria must be present for nodulation of the roots (Williams, Love and Berry, 1957).

Seeding. From 1 to 10 kg of seed per hectare should be drilled or broadcast. If the soil is extremely infertile and supporting practically no growth of native plants, use rose clover alone. If there is a fairly good cover, a mixture of 50 percent rose clover, 25 percent subclover, and 25 percent crimson clover should be used. Seeding should be done in the fall (Love, Dorman and Sumner, 1952).

Fertilization. Rose clover is strikingly responsive to fertilization with phosphorus and sulphur. In a study carried out during the 1955-56 year near Lincoln (California) applications of superphosphate to a stand of rose clover increased forage production over 300 percent and improved forage quality by increasing the protein content 70 percent and phosphorus level in feed 66 percent (Figure 10) (Johnson, Williams and Martin, 1956).

Utilization. Rose clover is highly appreciated by all kinds of livestock. It must be grazed in late spring/early summer, otherwise it will provide less attractive grazing than earlier. The relative unpalatability of dry rose clover was the primary reason for failure in an attempt to spread rose clover over the range in livestock manure (Green and Graham, 1958). Rose clover seedlings compete well and survive when introduced into a stand of residual annuals. Dissemination of seed by livestock, therefore, is an appealing idea since it avoids the costly operation of seedbed preparation (Love, Dorman and Sumner, 1952).

Rose clover may be included in the seeding mixture. It grows in the shade of tall grasses. Except in the early bloom stage, it has also some tolerance for sprays which may be used on brush seedlings following brush clearance.

Rose clover has also some advantages when grown on grainland: (1) It will do well on soil types that do not support a good growth of subclover. (2) It will provide a good aftermath feed to supplement the cereal stubble. (3) It will volunteer in succeeding years and add nitrogen to the soil, thus aiding the grain crop.

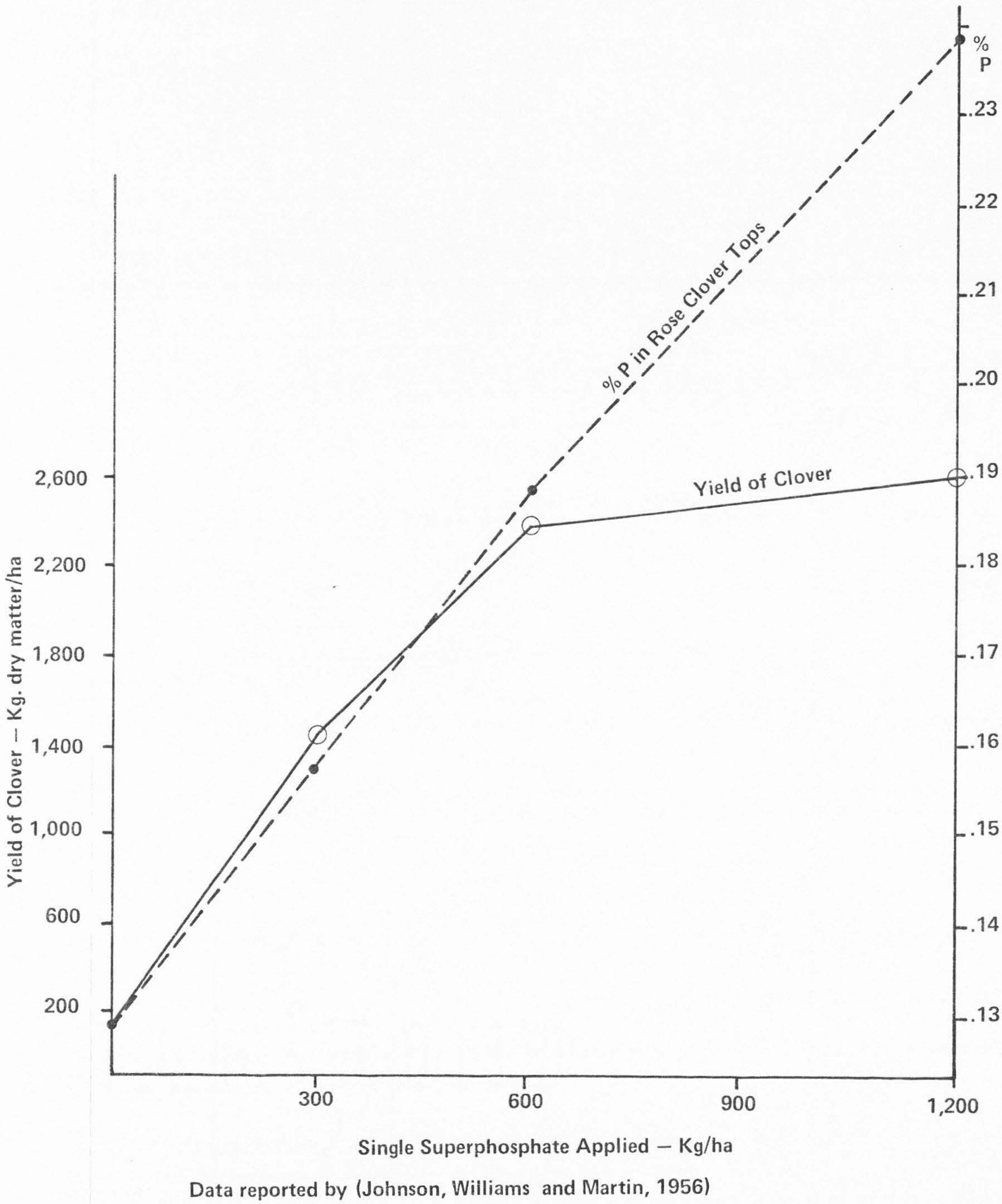

Figure 10. Yield and phosphorus content of clover as influenced by superphosphate applied in Placer County, 1956.

Gradually it builds up the soil to the point where it will support more and more growth of desirable forage plants. A striking example is a ranch in Santa Clara County (California) where the soil become very thin and would not support vegetation. The soil was improved through use of rose clover, which built up the depleted nitrogen supply (Williams, Love and Berry, 1957).

Summer annual weeds are controlled by vigorous stands of rose clover. It has been also unusually free of the insect and disease pests which frequently afflict other forage plants (Love, Dorman and Sumner, 1952).

Steps toward range improvement. Rose clover or a mixture of annual legumes should be seeded before the fall rains begin.

At the time of seeding, superphosphate should be applied, or soil amendement that encourage legume growth.

Only one subdivision of the range that should be grazed heavily before the annual grasses head out in the spring.

The stock should be kept off the grazed subdivision until fall.

The steps above may be applied to a new field each year.

A good pest-control program should be planned (Love, Dorman and Sumner, 1952).

Perennial true clovers

Red clover (Trifolium pratense)

Red clover is the most widely grown of all the true clovers. It is used for hay, pasture, and soil improvement and fits well into three- and four-year rotations.

Red clover is thought to have originated in Asia Minor and Southern Europe (Heath, Metcalfe and Barnes, 1973).

Description. Red clover is a short-lived perennial but in field culture it acts as biennial. However, in any population of red clover plants, even though most of them live only two years there are some that will live through the second winter and act as true perennials.

Red clover is a herbaceous plant made up of numerous leafy stems rising from a crown. The rosepink flowers are borne on heads at the tip of the branches. Heads usually consist of up to 125 flowers (Wilsie, 1949). Most strains, when grown under favorable conditions, have corolla tubes 9-10.5 mm in length. The corolla tube plays an important role in pollination and honey production in red clover pasture (Starling, Wilsie and Gilbert, 1950). Seeds are short and mitten-shaped, 2-3 mm long, and vary in color from pure yellow to purple. The roots are much branched, deep feeding, and are well supplied with nitrogen-gathering tubercles when well inoculated (Wheeler, 1950).

Distribution and adaptation. All red clover may be grouped into three divisions: early flowering, late flowering, and wild red. The latter is not well known. Most of the red clovers are of the early flowering type which is characterized by the production of two or three hay crops per year. The late flowering type or single-cut type usually produces one crop plus an aftermath. The major difference between the two types is related to daylength response, the single-cut type requiring a longer photoperiod (Ludwig, Barrales and Steppler, 1953).

Red clover is best adapted where summer temperatures are moderately cool to warm and adequate moisture is available throughout the growing season. Fertile, well-drained soils of high moisture-holding capacity are best for red clover. Red clover will grow on moderately acid soils, but maximum yields are obtained only when Calcium is adequate and the pH is 6 or higher.

Phosphorus is used in large quantities by red clover. This is the limiting factor on most red clover pastures. Potassium also is needed for direct benefit (Heath, Metcalfe and Barnes, 1973).

Obtaining a stand. A good establishment of red clover requires a firm seedbed (Wheeler, 1950).

Red clover usually is sown with a small-grain companion crop. It is apparently quite tolerant of shading. It has been suggested that photosynthetic saturation for isolated plants of red clover was reached near 16,000lx of white light, which is fairly low light intensity (Bula, 1960).

Early spring seeding is favored for red clover establishment, generally in February or March. When seeded alone, the usual rate is 9-11 kg/ha. Red clover is usually seeded in mixtures with a grass, in which case 4.5-7 kg/ha is usual (Heath, Metcalfe and Barnes, 1973).

Addition of phosphorus, potash, and lime has sometimes proved necessary. Phosphorus can be supplied readily by the use of 200 to 300 kg of 18 percent acid phosphate per hectare. For potash addition of 50 kg of muriate of potash is helpful. When lime is needed, a ton of finely ground limestone can be used (Wheeler, 1950).

Utilization and benefits. Red clover has many uses in range improvement and management.

Red clover as pasture. Red clover is an excellent pasture for all livestock, especially while they are growing. Ordinarily red clover will furnish some pasture during the first fall after spring seeding. It should not be grazed too closely at this time, or else the succeeding season's hay crop may be decreased. The plants should rather be allowed to go into the winter with some growth in order to prevent and also enable them to store up material in the roots for an early vigorous growth the following spring (Wheeler, 1950).

Pasture mixtures and renovation. Red clover is used extensively in pasture mixtures and for renovating old pastures. It is the easiest legume to establish in closely-grazed or renovated sods.

The inclusion of grass in red clover pastures is desirable to control soil erosion, and cattle are less likely to bloat on mixtures than on clover alone. Reproductive disturbances of livestock also have been reported from grazing of predominantly red clover pastures. They are apparently caused by the estrogenic activities of the isoflavones (Heath, Metcalfe and Barnes, 1973).

Red clover in rotations. Rotational rather than continuous grazing will result in longer life of the red clover stand. These rotations may be of various kinds and may include one or two crops of corn or other cultivated crop, one or two crops of small grain, of which one or both may be fall or spring sown, and the clover or clover-and-grass stand may be left for one, two, or more years (Wheeler, 1950).

Red clover as a soiling crop. Where pasturing is impractical, red clover is sometimes used as a soiling crop; that is, cut and fed green to livestock. This method makes a good early feed and eliminates the danger of bloating.

Red clover as hay. Red clover leaves contain three times as much protein as the stems and the heads contain about twice as much. The stage of maturity of the plants at the time the first crop is cut has a marked influence on total yield of forage, actual and potential seed yields, and the quality of forage (Wheeler, 1950).

Red clover as silage. Silage has been made from red clover as from other legumes, but the process is always risky and rarely satisfactory. If a red clover crop is too mature to make a leafy hay and one that will be eaten without waste, it can usually be made into a silage that conserves more of the leaves and will be consumed with practically no waste.

Seed production. Red clover seed production depends upon pollination by honeybees and insects. The presence of more attractive nectar-producing plants in the vicinity is a factor. Red clover seed is usually taken from the second crop. The seed average production is 250 kg per hectare (Villax, 1963).

Diseases and insects. Red clover is subject to a number of diseases. Crown rot attacks red clover in winter and early spring at relatively low temperatures. Anthrachnose is a major disease in the cooler parts of the red clover pastures.

The red clover root borer often kills the plants by the end of the first crop year. Another insect which causes considerable damage is the clover root curculio (Heath, Metcalfe and Barnes, 1973).

Red clover strains. There are two strains of red clover in general use. Broad red clover, better known as cow grass, a vigorous biennial, and Montgomery red clover, a slow-growing perennial strain. Cow grass is an erect, early, high-producing strain which has always been held in high regard in temporary pasture for hay and for early summer, autumn and early spring grazing. Its vigorous erect habit enables it to compete successfully with other improved species such as ryegrasses, subclover and white clover, so that it is of considerable value in supplementing permanent pasture mixtures in the first two years.

Montgomery red clover is a more perennial, leafy strain which is better adapted for close grazing and is therefore regarded as being more suitable for permanent pasture than cowgrass (T. W. Martin, 1960).

Alsike clover (*Trifolium hybridum*)

Alsike clover is a perennial, although it is often treated agriculturally as a biennial. Its history is somewhat obscure, but it is believed to have originated in Sweden.

Description. Alsike clover resembles red clover in growth habit, but has pink flowers, is softer and more slender. Stems and leaves are smooth, heads are somwhat smaller than red clover. The seeds are about one-third the size of red clover and are various shades of green mixed with yellow (Whyte, Leissner and Trumble, 1953).

Adaptation. Alsike clover prefers a cool climate. Its home on the Scandinavian Peninsula shows that it is fitted to withstand cold weather.

Alsike clover prefers a rather heavy silt or clay soil with plenty of moisture. It will do well on soils that are too acid for red clover and also will tolerate more alkalinity than most other clovers.

Alsike clover is tolerant of wet and slightly saline conditions. It could be useful as a supplement to other clovers in the reclamation of a poorly drained area (T. W. Martin, 1960).

Establishing a stand. The time and method of seeding is much the same as for red clover. The usual rate of seeding is 4.5-7 kg/ha. On wet, acid soils alsike clover is often sown with redtop (*Agrostis alba* L.), but probably its greatest use is in mixture with red clover and timothy (Heath, Metcalfe and Barnes, 1973).

Utilization and benefits.

Alsike clover in mixtures. Alsike clover, except when grown especially for the seed crop, is almost always mixed with one or more grasses or other legumes. Besides the mixture of alsike clover, red clover and timothy, which is by far the most common one in use, various other mixtures are recommended for different situations and sections (Wheeler, 1950).

Alsike clover as pasture. In pasture mixtures the vigorous growth of alsike clover enables it to hold its own against the competition of other plants and its persistence and self-reseeding provide for its continuance (Wheeler, 1950).

Hay. Alsike clover, though not usually as heavy a yielder as red clover, makes a better quality hay. Chemical analyses show that there is not much difference between red clover and alsike clover hay but that the latter may contain more digestible protein and have higher fuel values than red clover hay. Since alsike clover is a smooth plant, it makes a cleaner, less dusty hay than red clover (Wheeler, 1950).

Seed production. When sown for a seed crop, the sowing should be made on the poorer lands; on rich, lowlands, the growth is rank and the yield of seed may be small.

The estimated average production of alsike clover seed in the United States is around 600 kg per hectare and is obtained in Idaho (Wheeler, 1950).

Cultivars and strains. Variation within this species appear to be less than that found in red clover. The Canadian Department of Agriculture has released the cultivar "Aurora" which is outstanding in hardiness and seed yield.

Some evidence exists that tetraploid alsike clover may be more persistent and higher yielding than the diploid form. "Tetra" is a tetraploid cultivar developed in Sweden (Heath, Metcalfe and Barnes, 1973).

Disease and insect pests. In general, alsike is susceptible to many of the same diseases and insects that damage red clover. It is considered resistant, however, to anthrachnose (Heath, Metcalfe and Barnes, 1973).

White clover (<u>Trifolium repens</u>)

White clover, native to Europe, should be regarded as the basic legume for improved pasture in areas where the average annual rainfall exceeds 55.88 cm. Formerly regarded as suitable only for moist, fertile soils, white clover has now shown itself adaptable to a wide range of soil and climatic conditions (T. W. Martin, 1960).

<u>Description</u>. White clover is ordinarily a long-lived perennial plant. It is shallow-rooted and spreads by creeping branches (stolons) which root at the nodes. The flowers are white or pinkish. The three leaflets of white clover are free of hairs and frequently have sawtoothed margins and a whitish mark in the center. Under favorable conditions there are usually 75 to 150 seeds per head (Wheeler, 1960).

<u>Pollination</u>. White clover is practically self-sterile; that is, the florets have to be cross-pollinated before seed will form. The florets produce an abundance of easily accessible nectar and therefore are visited by all kinds of bees. Under different environmental conditions various types and forms of white clover have developed and survived, giving this plant a wide range of adaptations (Wheeler, 1950).

<u>Adaptation</u>. White clover, like all the other clovers, thrives best under cool, moist growing conditions in soils with plenty of lime, phosphate, and potash, but it will tolerate poor conditions better than some other important clovers.

White clover is best adapted to well-drained silt loam and clay soils of pH 6-7. It can be grown on sandy soils with adequate soil moisture and fertility. White clover is not tolerant of saline or highly alkaline soils (Heath, Metcalfe and Barnes, 1973).

Culture and management. Except when sown for seed production, common white clover is usually sown with grass.

The establishment of a grass-white clover pasture requires an adequate ratio of clover to grass in the seeding mixture. In almost all situations, 2-4 kg/ha of white clover are adequate. The white clover seed should be inoculated with the proper *Rhizobium*. Liming to achieve a minimum of soil pH of 6 is recommended and adequate Ca, P, and K should be supplied. Some soils require minor element fertilization (Andrew, 1960).

The main problem in the management of a grass-white clover pasture is the maintenance of the white clover component. It is generally accepted that the ideal balance of grass to clover for maintaining pasture productivity is about 2:1. Since dry matter yield decreases and crude protein increases with increased percentage of clover in the pasture, this ratio provides maximum production of dry matter and crude protein (T. W. Martin, 1960).

White clover pastures require rotational or controlled continuous grazing. If pastures are grazed continuously, the height of forage should be maintained at 5-15 cm. Management in the fall should allow good regrowth of clover and thus rooting of new stolons. If the white clover component disappears from a permanent pasture, it may be reestablished by proper renovation practices.

Importance and use. White clover is an excellent pasture plant growing in many parts of the temperate zones. It is preferably used in pastures, but is also suitable for hay and silage. It improves the soil where it is grown (Whyte, Leissner and Trumble, 1953).

White clover is outstanding among legumes, with consistently higher content of Na, P, Cl, and Mo. In the grass-white clover pasture the white clover supplies N to the grass, increasing production and protein quality of the forage. The transfer of N from white clover to grass is a direct movement of nitrogenous compounds from nodules to grass roots; a transfer of products of decomposition of nodules, roots, and aerial parts of the white clover; and a transfer of N compounds through the grazing animal. Estimates of N-fixing ability of grass-white clover pastures, obtained by comparing their production with that of grass pastures receiving different levels of N, are as high as 225 kg N/ha in the U.S. and twice this in the 10-month growing season of the North Island, New Zealand (Heath, Metcalfe and Barnes, 1973).

White clover is widely used in renovation of permanent pastures lacking legumes. The species is used as a cover crop, especially in orchards and in roadbank seedings as an N-fixing legume. White clover-grass mixtures contribute to soil conservation, watershed management programs, and protection of the environment.

The risk of bloat probably reduces the use of white clover in certain areas, but the danger can be minimized by proper management and methods of control (Heath, Metcalfe and Barnes, 1973).

White clover can also be used for seed production in two ways: harvest of a seed crop from an area predominantly utilized as a pasture, and growth and management as a highly specialized crop for seed only. In Morocco the average seed production yield is about 300 kg/ha (Villax, 1963).

Varieties of white clover. White clover may be divided into three general types: (1) the large type represented by the variety Ladino, (2) the intermediate type, as in the naturalized Louisiana strain, and (3) the low-growing type, represented by the New York and English wild white varieties. These differ principally in growth, size, performance, and other characteristics, and variation occurs within them (Wheeler, 1950).

During the 1950's and 1960's in the U.S., breeding programs developed the improved cultivars of white clover listed in Table 21 (Heath, Metcalfe and Barnes, 1973).

Diseases and insects. Stolon and root rots may seriously deplete stands of white clovers. This disease is probably responsible for what is often called excessive winter killing.

Pepperspot and sooty blotch are leaf diseases. They occur commonly, and when severe bring about defoliation and reduction of pasturage.

The glabrous leaves of white clover are especially susceptible to the potato leafhopper. Feeding by the insect causes stunting and browning of the leaves.

Ladino clover (*Trifolium repens* var.)

The phenomenal extension of popularity of Ladino clover in most ranges over the world is comparable to the extension of alfalfa and bromegrass far beyond the areas of earlier production. Under favorable ecological conditions, Ladino clover competes with all other

Table 21. Improved white clover cultivars in the U.S.[a]

Cultivar	Type	Year of release	Originator	Adaptation	Characteristics
Louisiana S1	Intermediate	1952	Louisiana station	Gulf Coast states	5-clone synthetic; reseeds well
Pilgrim	Large	1953	Northwest station and USDA	Northeast and Canada	21-clone synthetic; trueness to type
Merit	Large	1960	Iowa station	Central corn belt and northeast	30-clone synthetic; leaf-hopper damage and drought resistance; winter hardy
Regal	Large	1962	Auburn University station	Southeast	5-clone synthetic; persistence, summer production
Tillman	Large	1965	South Carolina station and USDA	Southeast	6-clone synthetic; summer production, persistence, disease resistance, sparse flowering, profuse stolon branching.

[a] Data reported by Heath, Metcalfe and Barnes, 1973.

forage legumes for first place as a pasture crop. It is rapidly becoming the foundation of an intensive grassland agriculture over a large part of the U.S. Its culture and soil requirements in some respects are more exacting than those of common white clover, but the diversity of its uses, its high carrying capacity for all classes of livesotck, the high nutritive value of the forages, and its general adaptation are important characteristics which give it a dominant position as a pasture crop. Although primarily a grazing crop, Ladino clover is being used also for hay and silage, particularly in combinations with grasses and other legumes and also as a cover crop.

Ladino clover appears to have come from and to have derived its name from Lodi, a town in the Province of Lombardy in Italy (Wheeler, 1950).

Description. Ladino clover is a large type of white clover with the same general habits of growth as the common white clover. It is a rapid-growing perennial spreading by creeping fleshy stems that root at the nodes. Ordinarily Ladino clover does not flower so profusely as most other types of white clover. In size and color Ladino seed is the same as that of other white clovers (Wheeler, 1950).

Adaptation. Ladino clover has about the same soil and climatic requirements as ordinary white clover. It is capable of surviving cold winters if given proper fertilization, proper grazing or cutting management, and compatible grass association.

Ladino clover has been considered as best adapted to the more fertile moisture-retaining soils in the ranges having relatively cool summer temperatures. Although it is not drought-resistant, it will tolerate periods without rainfall if associated grasses do not offer too much competition (Wheeler, 1950).

Establishing a stand. For early spring sowing, fall plowing is recommended, as it provides an opportunity for the soil to settle during the winter months. For fall sowing, the soil should be prepared during the summer months. Addition of substantial quantities of phosphates, calcium and potash is necessary for satisfactory plant growth.

Ladino clover may be sown alone or with grasses and other legumes.

Importance and use of Ladino clover. Ladino clover is altogether the most promising pasture legume in most areas. All classes of livestock have been grazed on Ladino clover or Ladino-clover-grass mixtures with excellent results. In feed value, this plant is equal or superior to other forage legumes. It is very palatable, high in proteins, minerals and vitamins, and low in fiber. Ladino clover appears to give up as much or more nitrogen to associated grasses than any other legume, and is a valuable soil-improving crop. It is an excellent crop in pasture mixtures, either with grass or with other legumes, or with both grasses and legumes. Under proper management, Ladino clover, with a compatible grass combination in areas where both are adapted, can produce more and better pasture than any other legume-grass mixtures. It can do more to reduce the quantity of high-protein supplementary feeds required, and thereby the cost of livestock rations, than any other pasture legume since it is reestablished from natural reseeding. Through this latter characteristic it provides an excellent permanent ground cover which is effective in reducing water losses due to runoff and soil losses by erosion. It is also extremely aggressive under favorable conditions and retards the encroachment of most weeds and many undesirable grasses.

Ladino clover has unfortunately the disadvantage of not being as good a seed producer as common white clover. Therefore, the price of seed will probably be higher (Wheeler, 1950).

Strawberry clover (Trifolium fragiferum)

Strawberry clover is native to the eastern Mediterranean and southern Asia Minor countries. It has been observed in every continent of the world; and wherever it is grown the value of the pasture herbage has increased. In Australia its culture on low-lying overlow lands has become extensive (Hollowell, 1939).

Description. Strawberry clover is a perennial, low growing, pasture legume spreading vegetatively by creeping stems that root at the nodes. The leaves, stems, and habit of growth are somewhat similar to white clover, making it generally difficult to distinguish from certain types of white clover when not in bloom. The flower heads, seed pods, and seed are very distinctive, however, making floral identification easy. In general the flower heads are round, although sometimes they are slightly pointed, and in color they are mostly pink to white, resembling a strawberry, the common name. The seed color varies but is principally reddish brown or yellow flecked with dark marking. The seed is much larger than that of white clover but slightly smaller than red clover seed (Hollowell, 1939).

Adaptation. Strawberry clover thrives under wide extremes of temperatures ranging from 40° below zero to high summer temperatures. Its main value is in its relative tolerance of waterlogged, saline or drought conditions. For this reason it is recommended for sowing on areas which are too wet for white clover but not permanently waterlogged. It is also useful in highly alkaline soil and in the reclamation of areas where pasture growth is beginning to decline through the accumulation of salt (G. J. Martin, 1960).

Strawberry clover is extremely valuable for large areas in most irrigation projects, where drainage is a limiting factor in crop production. A valuable characteristic is its ability to survive flooding for one to two months without the plants being killed. Although it will live under relatively dry conditions and will survive short periods of drought, the clover will not make sufficient growth to warrant its use on dry land (Hollowell, 1939).

Culture. Preliminary studies to determine the best methods of sowing indicate that where possible, a seedbed should be prepared in the fall by plowing or disking thoroughly, followed by harrowing to level and firm the soil.

Sowing should be done in the early spring. The seed may either be broadcast or drilled in very shallowly with a rate up to 5 kg per hectare.

If the seedings are made on a prepared seedbed, it is not often that the other vegetation will crowd out the seedlings and prevent their establishment. When the seed is broadcast, however, without seedbed preparation, rushes and sedges are very apt to crowd out the seedlings. Mowing to reduce this competition is, therefore, highly desirable and should be done. After the seedling plants are well established the range may be grazed. Grazing is very desirable for two reasons: (1) the grass and sedges are grazed with the grazing of the clover, which reduces the competition to the benefit of the clover, and (2) the sedges and rushes are trampled, which also retards their growth, giving the clover more opportunity to spread (Wheeler, 1950).

Utilization. Strawberry clover is principally a pasture plant, though it may be used as a green-manure crop, particularly on ranges where salinity prevents the growth of other legumes. It is very palatable to all kinds of livestock and is rich in animal feed units. When the plants are grown on saline soil range the composition of the vegetation is somewhat high in minerals and this salinity has no harmful effect on animals. Like other legumes, strawberry clover may cause animals to bloat and necessary preventative measures should be taken. Strawberry clover has the great benefit of increasing soil fertility in nitrogen.

Strawberry clover will survive under close grazing, but it may be more productive if grazed moderately. Close grazing, on the other hand, will reduce the number of many of the other less desirable plants and in that way will encourage the spread of the clover and the development of a good sward turf. It has been grazed continuously from early spring until late in the fall without affecting the stand, although rotational grazing would probably favor greater production. With an increase of the salt concentration of the soil to the point where growth is inhibited the advisable practice is to remove the animals until the clover makes additional growth.

Ranchers who have used large acreages for grazing claim that on similar soils the carrying capacity of strawberry clover is far superior to that of other pastures. Many claim that 1 hectare will carry from 2 to 4 cattle through the entire growing season provided growing conditions are favorable. The blossoms of strawberry clover are visited by honeybees. Apparently the bees obtain considerable nectar, which indicates this is a good honey plant although it is self-fertile (Hollowell, 1939).

In addition, strawberry clover is a prolific seed-producing plant if properly handled. Yields range from 40 to 300 kg.

The True Clover Failure

The previous section pointed out the specific characteristics of each true clover species, their importance in range improvement and particularly their conditions and requirements that we must respect to achieve their full potentialities and benefits.

The too frequent failure to get a stand of true clover has several causes. Nevertheless, the most important of these is lack of appropriate fertilizers in the soil and their inappropriate application. Another is loss of organic matter by reason of unwise methods of ranching. Use of an adapted seed, inoculation, and in some ranges, diseases have a good impact on clover production.

Frequent clover failures have been experienced to some extent in ranges all over the world. Many factors have worked toward this end, but they may be placed in five groups: (1) soil exhaustion, (2) unadapted seed, (3) improper methods of sowing, companion crops, etc., (4) diseases, and (5) improper treatment the first growing season. True clovers fail more often because soils have become poor in phosphorus, lime, potash, and microelements, than for all other reasons. If lime is badly needed there is no use sowing clover seed unless sufficient lime is added. If phosphorus is the limiting factor, the addition of lime alone, even if the land is sour, will have slight effect according to Liebig's law of minimum.

Improper methods of fertilizer application are also responsible for the failure of true clovers. For instance, application of phosphorus fertilizers by broadcasting in sandy soils will be a waste, since this material will be immobilized by Al and Fe ions present in the soil. In this case, application of phosphorus by banding will be the best way. Also the time of fertilizer application has an effect in avoiding losses by leaching and volatilization.

Improper methods of sowing, etc., are frequently responsible for the failure to get even the start of a stand or for the death of the plants after grain harvest. A poor seedbed, poor seed, weeds, careless sowing, or too heavy a companion crop may cause the early destruction of the small plants. If the season is dry, the vigorous companion grain grass will take the moisture and leave the clover seedlings to dry up, or the tender plants cannot endure the sudden exposure to a hot sun.

The total yield of forage clovers may be cut down, and in some cases destroyed, by the various insect or fungal troubles.

I believe that most of the factors already cited that lead to the failure of true clovers could be solved by an appropriate and good management program.

Potential Health Hazards

Apart from the presence in pasture, or associated with it, of plants that contain substance that are toxic or harmful to animals that graze them, some of the valuable and widely used pasture species, among them the true clovers and other legumes, under certain circumstances may cause disorders in grazing animals. In this section, some of the animal disorders of this type that occur most often in clover pastures, and that have been subjected to a considerable amount of study in many countries, particularly in Australia, are reviewed.

Bloat

Bloat is a widespread and serious trouble in cattle and sheep. It is characterized by the accumulation of gas in the rumen. It most frequently occurs when these animals are pastured on alfalfa or clover.

A recent estimate has placed the annual economic loss from bloat in Tasmania in excess of $400,000 per annum. This sum is all the more staggering when it is remembered that bloat is a strictly seasonal disease, being confined to not much more than three months of the year (Bennett, 1960).

Causes. The accumulation of gas results because excessive frothing and the formation of a stable foam during rumen fermentation interfere with the normal elimination of the gas by belching. A number of factors has been found to contribute to foam formation, notably soluble proteins in fresh forage, saponins, salivary micro-proteins, and special slime-producing bacteria (Maynard and Loosli, 1969).

Prevention and treatments. Several preventative measures and treatments have been evolved to minimize the losses from bloat. They include:

1. Pasture control. As it seems we cannot dispense with clovers--because of their multiple advantages--we must attempt to prevent pastures from becoming dominated by clover (Bennett, 1960).

2. Grazing control and livestock distribution over the range. Intensive strip grazing using electric fences.

3. Grazing management including the use of grass-legume mixtures rather than the legume alone; supplementation of legume pastures with good quality grass hays fed overnight; or cutting and feeding the legume herbage in dry lot (Heath, Metcalfe and Barnes, 1973).

4. Use of anti-foaming agents, such as oil, have a protective effect, but only for a short period for a given dose. Experiments have shown that the addition of the oil to the drinking water has a continuous beneficial effect. More satisfying results have been obtained by spraying the anti-foaming agent on the fresh forage, a method which has been used frequently in Australia (Maynard and Loosli, 1969).

5. Feeding of antibiotics. The administration of antibiotics in the food has been successfully used to reduce fermentation in the

rumem. Penicillin has proved to be the only antibiotic without undesirable side effects (Bennett, 1960).

The long-term solution to the problem of bloat would seem to lie in programs of plant breeding designed to select legume species and cultivars of low bloating potential and adequate nutritional quality and of selection of animals with a low hereditary susceptibility to the disease. Some progress in this direction has been made (Reid and Jung, 1973).

Phyto-oestrogen in pasture legumes--clover disease

Of the pasture legumes, some of the most important have been found to cause oestrogenic effects in the animals that graze them. The main species involved are subterraneum clover, red clover, and several medics. The phyto-oestrogens that have been identified in the pasture plants under consideration fall into two main groups--the isoflavones and the coumestans. The former are the major phyto-oestrogens in clover and the latter in the medics (Braden and McDonald, 1973).

Interest in the oestrogenic compounds present in forage plants first developed with the report of severe reproductive disorders in ewes grazing subterraneum clover pastures in Australia. It was considered that breeding failures ("clover disease") were caused by the consumption of excessive amounts of subterraneum clover which has been shown to contain the oestrogen genestein.

It has been shown that subterraneum clover is dangerous from germination to wilting time, after which there is a rapid loss of toxicity (Lightfoot, Croker and Neil, 1967).

There is a variety of manifestations of clover disease (Bennett, 1960).

Dead lambs. Some affected ewes give birth to dead or weak lambs. Dystocia is common.

Infertility. White clover disease may appear in the first year in the form of many distocias, in subsequent years infertility is the most notable feature and could be irreversible (Figures 11 and 12).

Prolapse of breeding organs. Prolapse of the uterus is common in clover disease and deaths are likely from infection and toxemia.

High tail. The action of the clover oestrogen on the ligaments of the pelvis and sacrum results in a condition described as high tail, which does not always appear to affect the health of the ewe but is indicative of excessive intake of subterraneum clover.

Effect on wethers. The effect of clover oestrogen on wethers is twofold: it induces lactation and produces a condition referred to as false bladder.

The control for clover disease is to prevent ewes from regularly eating excessive amounts of green subterraneum clover of any strain.

The theory that fertilizer treatments may influence the oestrogenic potency of subterraneum clover was investigated. Clover receiving no fertilizer was significantly more potent than clover which had received fertilizer.

Other diseases could occur occasionally by an excessive consumption of legumes, but they are less important than those cited above.

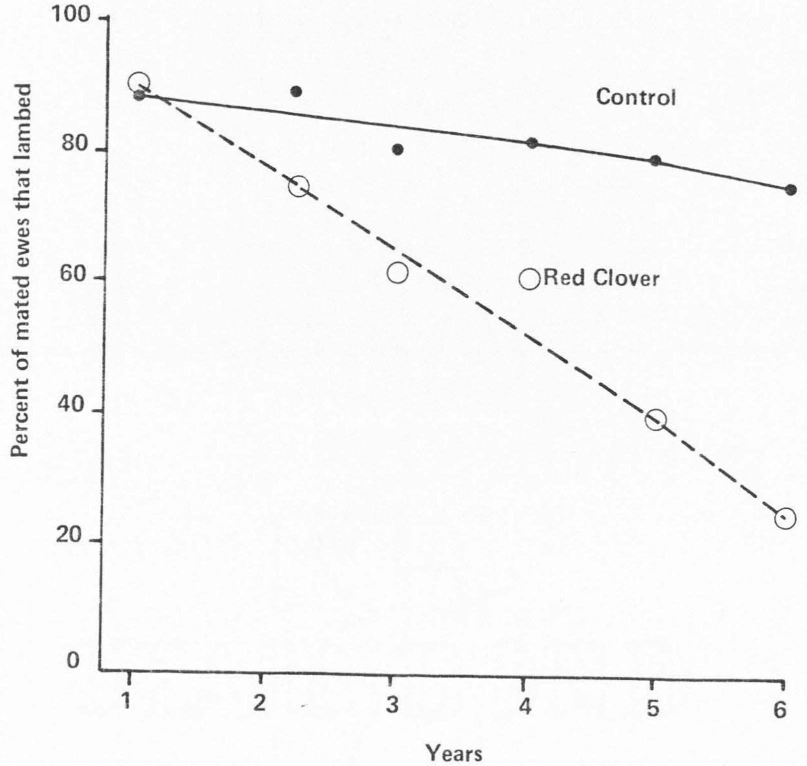

Figure 11. Decline in fertility in Merino ewes associated with grazing oestrogenically active red clover pastures for 8 months in each year.

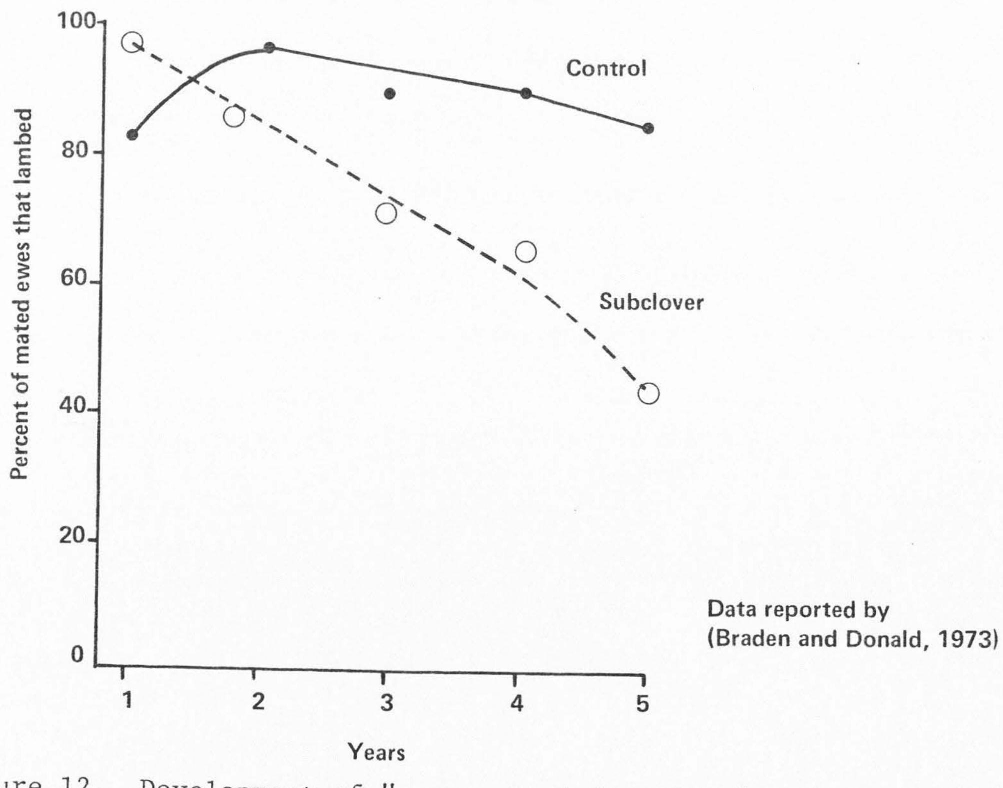

Figure 12. Development of "permanent infertility" in a flock of cross-bred ewes that grazed Trifolium subterraneum for 6 months each year.

APPLICATION OF LEGUMES IN SEMI-ARID RANGELANDS, WITH PARTICULAR REFERENCE TO MOROCCO

The semi-arid rangelands occupy large areas around the world. According to the calculations of UNESCO and FAO more than a third of the earth's surface may be classed as falling within the semi-arid and arid zones (Stamp, 1962). These areas are characterized by low annual rainfall (250-350 mm) with an irregular distribution, high evaporation, and low fertility. These factors make these regions unsuitable for crops. The most obvious use is for pastures and livestock production.

Morocco is relatively a dry country. With the exception of coastal fringes, mountainous regions and some interior plains, the country can be considered in the semi-arid or arid zone by any climatic definition. These sites, which are continually being utilized for livestock production, become more and more degraded and areas of climax vegetation are rare or nonexistent. The annual production of forage becomes small while the animal demand increases progressively. The decline in productivity in semi-arid rangelands in Morocco can be assumed to have resulted from the following conditions.

1. High market demand for red meat resulting from the high population increase which is about 3 percent per year, or in other words, the population is increasing by 500,000 people every year. This rapid population increase requires an increase in food supply and particularly in proteins.

2. Herdsmen and businessmen concentrate on increasing their numbers of livestock. As a result, the carrying capacity of the usable range in these areas decreases.

3. Range management and range improvement programs are still in the experimental stage.

4. Morocco is suffering a lack of specialized technicians in range management.

So, there is no other remedy but to effect rangeland development in a way that will provide adequate nutritional requirements, by making use of technical advances in this field.

The concept of development of Moroccan semi-arid rangelands is almost synonymous with increasing the forage quantity and quality, building up the soil fertility and structure by the cheapest means, and the establishment of long-term grazing management programs. In order to attain these objectives, the establishment of permanent legume pastures seems to be the best approach. Many experiments on legume utilization have been carried out in semi-arid rangelands around the world, particularly in Southern Australia, California, and Portugal. In Morocco, the best example known to me is the experiments conducted in Mamora Forest by Maignan and Ibnattya in 1972. The objectives of these experiments were to observe the behavior, adaptation, and production of *Trifolium* and *Medicago* species in a typical semi-arid area. The annual precipitation in the study area is about 350 mm and confined to the late fall, winter and early spring. The soil is sandy clay and the natural vegetation is a *Quercus suber* overstory with *Genista linifolia* and other herbs as understory. The average production of natural green forage has been estimated to be 1500 kg/ha/year (Ibnattya, 1972).

The different randomized plots in this study received an equal and adequate amount of superphosphate (45 percent--P_2O_5).

In late spring, the legume plots showed increased yields compared to the natural vegetation (Table 22).

In the two years following, production was better than during the first year. This was due probably to the increase in soil fertility, caused not only by the addition of superphosphate but also by the raising of the nitrogen content of the soil due to symbiotic fixation. Similar improvements have been obtained by the cultivation of *Hedysarum coronarium* in a semi-arid rangeland around Fes. This species was cultivated on a watershed in order to evaluate not only its forage production but also its ability to prevent soil erosion.

The invaluable results obtained from these experiments have been the subject of many discussions and seminars. They have stimulated the Morroccan agricultural officials to look closely at the improvement of semi-arid rangelands and especially at the potential use of *Trifolium* spp.

Table 22. Production of some strains of *Trifolium* spp. and *Medicago* obtained in Mamora Forest in Morocco (Maignan and Ibnattya, 1975).

Strains	Species	Production of green matter (kg/ha)
Clare	*T. subterraneum*	28,100
Horbinger medic	*Medicago*	18,200
Cyprus barrel	*Medicago*	15,900
Geraldton	*T. subterraneum*	13,300
Yarloop	"	11,800
Dwalganup	"	10,700
Seaton park	"	9,800
Ladino	"	5,200

USE OF LEGUMES, ESPECIALLY CLOVERS, IN UTAH RANGELANDS

In the light of our discussion of the subject of the legumes and especially clovers, it is important to point out their use in Utah rangelands.

There is no doubt that some legumes such as alfalfa grow successfully in Utah pastures. Nevertheless this success is more or less harder to obtain in this state than in others where favorable climatic and soil conditions exist.

One must ask a question: "Why do we not find clovers in Utah on rangelands?" There are many limiting factors for the growth of these species, but the most important are lack of rainfall, frost action, and the deficiency of soil in phosphorus. The clovers, as we discussed in the previous sections, even though having a broad climatic tolerance, require higher rainfall and minimum temperature than those occurring in most parts of Utah. These two elements contribute not only in the seed germination but particularly in the microbial activity and symbiotic process.

The deficiency of Utah's soil in phosphorus handicaps severely the clover's success. This deficiency affects the rate of protein synthesis, the infection stages of nodulation, and the maintenance of rhizobial population. Addition of large amounts of superphosphate in some areas where temperature and rainfall are quite adequate may aid in the clover establishment. Nevertheless, some economical research must be taken into consideration.

SUMMARY

Today's world population explosion has generated a massive hunger problem. Legumes are essential as human food and livestock forage in the effort to cope with the protein deficiency. They are also important in soil conservation and range improvements. In many areas, inorganic nitrogen fertilizers are expensive or even unavailable. Fertile soils rank among any nation's resources. The association of rhizobia and leguminous plants is unique. The symbiotic N fixation mechanism is a beneficial as well as an inexpensive phenomenon. Nitrogen is the most abundant element in our atmosphere and a key element of all living organisms. Thus any failure to profit from this mechanism available in leguminous plant culture is not in keeping with sound management.

In the legume family, the true clovers (Trifolium spp.) are the best species for range improvement, particularly in semi-arid rangelands. This genus comprises approximately 250 species. Its main center of origin is believed to be in Asia Minor and Southeastern Europe. Only about nine species are of range importance. They are annual or perennial herbs, mostly adapted to cool and moist climates. In regions with hot and dry summers, their growth in the absence of irrigation is confined to the autumn, winter, and spring. They grow best on soils rich in phosphorus, potassium, and calcium. Most clovers are long-day plants but there are exceptions. Most true clovers are trifoliate and carry the flowers in head-like inflorescences. These heads may have a large number of flowers, as in red

clover (up to 100), or only a few, as in subterranean clover. Some species (red, alsike, and white clover) are almost completely self-sterile and need to be cross-pollinated for seed setting. Others are self-fertile and self-pollinating. The number of seeds per pod varies according to the species from one to eight.

The true clovers do well on brush burns, annual type ranges, and grainland. Their mixture with other grasses provides good forage quality and plentiful food in spring and makes good dry feed in summer and fall. Their self-regenerating habit is an important economic factor.

The need for seed inocualtion, seedbed preparation, fertilization, and time of seeding varies with different species.

Management and utilization practices differ also from one species to another and must be taken into account to attain the maximum yields and the full success.

LITERATURE CITED

Adams, W. E., and M. Stelly. 1958. A comparison of coastal and common bermudagrass, Cynodon dactylon (L.) Pers., in the Piemont region: yield response to fertilization. Agron. J. 50:457-59.

Aitken, Y. 1955. Flower initiation in pasture legumes. Aust. J. Agr. Res. 6:212-44.

Anderson, A. J., and D. V. Moye. 1952. Lime and molybdenum in clover development on acid soils. Aust. J. Agr. Res. 3:95-110.

Andrew, C. S. 1960. The effect of phosphorus, potassium, and calcium on the growth, chemical composition, and symptoms of deficiency of white clover in a subtropical environment. Aust. J. Agr. Res. 11:149-61.

Bartholomew, W. V., and F. E. Clark. 1965. Soil nitrogen. American Society of Agronomy, Madison.

Beggs, J. P. 1964. Spectacular clover establishment with formalin treatment suggests growth inhibitor in soil. N.Z. J. Agric. 108:529-35.

Bennett, S. 1960. Disorders of animals caused by legumes. J. Austr. Inst. Agric. Sci. 26:42-48.

Bergerson, F. J., J. Brockwell, and J. A. Thompson. 1958. Clover seed pelleted with bentonite and organic material as an aid to inoculation with nodule bacteria. J. Aust. Inst. Agric. Sci. 24:158-60.

Boullard, B. 1967. Vie intense et cachee du sol. Essai de pedobiologie vegetale. Flammarion, Paris.

Braden, W. H., and I. W. McDonald. 1973. Disorders of grazing animals due to plant constituents. Pages 381-391 in R. M. Moore (ed.), Australian Grasslands. Aust. Nat. Univ. Press, Canberra.

Bula, R. J. 1960. Vegetative and floral development in red clover as affected by duration and intensity of illumination. Agr. J. 52:74-77.

Burns, R. C., and R. W. F. Hardy. 1975. Nitrogen fixation in bacteria and higher plants. Springer-Verlag, New York.

Crespo, D. G. 1970. Some agronomic aspects of selecting subterraneum clover from Portuguese ecotypes. Offprint from proceedings of the XI International Grassland Congress. Univ. Queensland Press.

Donald, C. M. 1960. The impact of cheap nitrogen. J. Aust. Inst. Agri. Sci. 26:319-349.

Donald, C. M. 1973. Temperate pasture species. Pages 303-320 in R. M. Moore (ed.), Australian Grasslands. Aust. Nat. Univ. Press, Canberra.

Donald, C. M., and C. H. Williams. 1954. Fertility and productivity of podzolic soil as influenced by subterraneum clover and superphosphate. Aust. J. Agric. Res. 5:665-687.

Graham, E. H. 1941. Legumes for erosion control and wildlife. U.S.D.A. Miscellaneous Publication No. 412.

Green, L. R., and C. A. Graham. 1958. Annual legumes on granitic soil in the central Sierra foothills. Calif. Forest and Range Exp. Sta. Tech. Paper 24. p. 11.

Heath, M. E., D. S. Metcalfe, and R. F. Barnes. 1973. Forages, the science of grassland agriculture. 3rd ed. The Iowa State Univ. Press, Ames, Iowa.

Holmgren, A. H. 1972. Handbook of the vascular plants of the Northern Wasatch. Utah State Univ., Logan, Utah. p. 202.

Hollowell, E. A. 1939. Strawberry clover. U.S.D.A. Leaflet 176.

Hollowell, E. A. 1947. Crimson clover. U.S.D.A. Leaflet 160.

Horner, G. M., M. M. Overson, G. O. Baker, and W. W. Pawson. 1960. Effect of cropping practices on yield, soil organic matter and erosion in the Pacific Northwest wheat regions. Published cooperatively by the Agric. Exp. Sta. Idaho, Oregon, Washington, and the Agric. Res. Serv., U.S.D.A. Bulletin 1.

Ibnattya, A. A. 1972. Inventaire sylvo-pastoral dans la foret de la Mamora. Chaire d'amenagement des parcours. E.N.F.I. Sale, Morocco.

Johnson, W. H., W. A. Williams, and W. E. Martin. 1956. Rose clover. Yield and quality. Journal of Reports and Progress in agricultural research, University of California 10(2):7, 8, 11, 12.

Kjar, N. A. M. 1960. Importance of pasture legumes to Tasmania. J. Aust. Inst. Agric. Sci. 26:79-83.

Knight, W. E. 1967. Effect of seeding rate, fall disking, and nitrogen level on stand establishment of crimson clover in a grass sod. Agron. J. 59:33-36.

Lamborn, R. E. 1977. Personal communication. Utah State University, Logan, Utah.

Lancaster, R. R. 1944. Pasture clovers. Tex. Livest. J. 3:6, 10, 70.

Le Houerou, H. N. 1975. Personal communication. Mission FAO Project Education et formation forestieres. Mor 519/SF/0387.

Lightfoot, R. J., K. P. Croker, and H. G. Neil. 1967. Failure of sperm transport in relation to ewe infertility following prolonged grazing on oestrogenic pastures. Aust. J. Agric. Res. 18:755-65.

Loneragan, J. F. 1960. Pasture legumes in Tasmania. J. Aust. Inst. Agric. Sci. 26:26-32.

Love, R. M. 1951. Rose clover running high in California popularity. Reprinted from Western Feed and Seed, October.

Love, R. M. 1959. The range-natural plant communities or modified ecosystems? Personal communication. Revised from an address presented at a plenary session of Amer. Soc. Range Mgt. and Amer. Grassland Council, Tulsa, Oklahoma.

Love, R. M., C. Dorman and D. C. Sumner. 1952. Rose clover, a new winter legume. Cal. Agr. Exp. Sta. Cir. 406. 11 p. Illust.

Ludwig, R. A., H. G. Barrales, and H. Steppler. 1953. Studies on the effect of light on the growth and development of red clover. Can. J. Agr. Sci. 33:274-87.

Maignan, F. 1973. Cours d'amenagement des parcours. ENFI et projet FAO/SF/PNUD. MOR 68-519/SF/0387.

Maignan, P., and A. A. Ibnattya. 1975. Resultats des differents essais sur le trefle souterrain en foret de la Mamora. ENFI et FAO/SF/MOR 68/519.

Martin, G. J. 1960. The relative importance of legume species in improved pastures. J. Aust. Agric. Sci. 26:38-42.

Martin, T. W. 1960. The role of white clover in grassland. Herb. Abst. 30:159-64.

Maynard, L. A., and J. K. Loosli. 1969. Animal nutrition. 6th ed. McGraw-Hill Book Company, New York.

McKell, C. M., and A. M. Wilson. 1963. Effects of temperature on S^{35} uptake and translocation by rose and subterraneum clovers. Agron. J. 55:134-37.

Michael, P. W. 1973. Weeds of grasslands. Pages 349-360 in R. M. Moore (ed.), Australian Grasslands. Aust. Nat. Univ. Press, Canberra.

Miles, A. D. 1957. Natural sources of nitrogen and phosphorus for grass growth. J. Range Manage. 11(1):125-128.

Milner, M. 1972. Nutritional improvement of food legumes by breeding. Symposium sponsored by Protein Advisory Group of the United Nations System. John Wiley and Sons, New York.

Mishustin, E. N., and V. K. Shiln'Kova. 1971. Biological fixation of atmospheric nitrogen. Penn. State Univ. Press.

Morley, F. W. H. 1962. Pasture plant breeding and animal production. J. Aust. Inst. Agric. Sci. 28:3-7.

Morrison, F. B. 1936. Feeds and Feeding. 20th ed. The Morrison Publishing Company, Ithaca, New York.

Moore, R. M. 1973. Australian grasslands. Aust. Nat. Univ. Press, Canberra.

Murphy, A. H., B. L. Kay, and C. M. McKell. 1962. Pre-emergence herbicide aids establishment of clovers in dryland pastures. Col. Agr. Exp. Sta. 16(7).

Powrie, J. K. 1964. The plant-nodules and nitrogen. Aust. Inst. Agric. Sci. Jour. 30:55-60.

Paton, D. F. 1960. Problems in legume establishment with special reference to nodulation and nutrition. J. Aust. Inst. Agric. Sci. 26:32-38.

Reid, R. L., and G. A. Jung. 1973. Forage-animal stress. Forages, the science of grassland agriculture. 3rd ed. Iowa State Univ. Press, Ames, Iowa.

Smith, R. L. 1974. Ecology and Field Biology. 2nd ed. West Virginia University.

Stamp, L. D. 1962. Land use in semi-arid mediterranean climates. Unesco/International Geographical Symposium. Iraklion (Greece).

Starling, T. M., C. P. Wilsie, and N. W. Gilbert. 1950. Corolla tube length studies in red clover. Agron. J. 42:1-8.

Stewart, W. D. P. 1966. Nitrogen fixation in plants. University of London, The Athlone Press.

Stoddart, L. A., A. D. Smith, and T. W. Box. 1975. Range Management. 3rd ed. McGraw-Hill Book Company.

Subcommittee on Dairy Cattle Nutrition, Committee on Animal Nutrition, Agricultural Board, National Research Council. 1976. Nutrient requirements of dairy cattle. 4th rev. ed. National Academy of Sciences, Washington, D.C.

Tisdale, S. L., and W. L. Nelson. 1975. Soil fertility and fertilizers. 3rd ed. Macmillan Publishing Co., Inc., New York.

U.S.D.A. 1960. Persian clover--a legume for the south. Leaflet 484.

U.S.D.A. 1976. Management and uses of rose clover. USDA Soil Cons. Serv., Davis, California. Mimeo.

Vallentine, J. F. 1974. Range development and improvements. Brigham Young Univ. Press, Provo, Utah.

Villax, E. J. 1963. La culture des plantes fourrageres dans la region mediterraneenne occidentale. INRA, Rabat, Morocco.

Waksman, S. A. 1927. Principles of Soil Microbiology. Baltimore, The Williams and Wilkins Company.

Wheeler, W. A. 1950. Forage and Pasture Crops. D. Van Nostrand Company, Inc.

Whyte, R. O., G. N. Leissner, and H. C. Trumble. 1953. Legumes in agriculture. F.A.O., Rome, Italy.

Williams, W. A., R. M. Love, and L. J. Berry. 1957. Production of range clovers. Calif. Agr. Exp. Sta. Serv. Cir. 458.

Williams, W. A., R. M. Love, and J. P. Conrad. 1956. Range improvement in California by seeding annual clovers, fertilization and grazing management. J. Range Manage. 9(1).

Wilsie, C. P. 1949. Producing alfalfa and red clover seed in Iowa. Agr. J. 41:545-50.

Wilson, P. W. 1940. The biochemistry of symbiotic nitrogen fixation. Madison Univ. Press, Wisconsin.

Young, J. A., R. A. Evans, and B. L. Kay. 1970a. Germination of cultivars of *Trifolium subterraneum* L. in relation to matric potential. Agr. J. 62:743-45.

Young, J. A., R. A. Evans, and B. L. Kay. 1970b. Germination characteristics of range legumes. J. Range Manage. 23(2):98-103.

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