" -- a land gleaming with furrows" - Wheat production in Australia

As Australia approaches with some excitement the 200th Anniversary of its Foundation, we can expect increasingly to be asked to reflect upon the history and progress of our institutions and industries. This evening we are concerned with the wheat industry and later I shall be making some observations about the significance of soil management for wheat production.

In the process, we shall be paying more than a passing tribute to William James Farrer, that giant amongst wheat breeders whose persistent vision impelled him to work so tirelessly to find the types of wheat which would succeed in our special conditions.

Like Virgil, the Roman poet from whose "Georgics" we have borrowed our title, he dreamed of "a land gleaming with furrows" in fact of opening up wider areas of agricultural enterprise of a virtual regenerationof the wheat industry.

For now the land is indeed gleaming with furrows since each year approximately 10 million hectares are sown to wheat which in the 1979-80 season produced sixteen million tonnes having a value of over 2,000 million dollars. Such production is significant because:

Mixed wheat-animal farms in Australia constitute the major component of our Agricultural system, which in total accounts for more than 40% of the nation's export earnings;

Also the industry has forward and backward linkages to other sectors of the Australian economic system. This is referred to as a "multiplier" effect which in years of underproduction, because of disease and drought, almost triples the impact of direct farm losses on the economy and thus has serious implications for manufacturing, service industries and employment generally.

We are all well aware that for a century the Agricultural Industry has done much to support Australia's development and as late as 1950 was responsible for 80% of our export earnings.

One should at this point try to dispel a common illusion connected with the fact that Australia is fourth amongst the world's wheat exporting nations. From this fact it is assumed by many that increased production and increased acreage in Australia will do much to feed the starving millions. Alas, this is not so, Australia produces only 4% of the world's wheat. As well, only 10% of world production of the principal cereals, wheat, rice and maize crosses international boundaries. Hence production must be increased within the needy countries themselves. The task is formidable because the world's rate of population growth is so great that in each and every week the equivalent of almost two additional cities the size of Adelaide has to be fed. However, the Australian cereal producer is very efficient and our science is advanced and sophisticated so that we are in a position to export "know-how" by means of technical aid and scientific advice.

We are here this evening to acknowledge the fact that the present state of the industry and indeed our disciplined, scientific approach to agricultural problems owes much to William James Farrer;

In an address to the Australian Association for the Advancement of Science delivered in Sydney in 1898 he provides the following comment:

> *"The idea of making improvements in the wheat plant was taken hold of as early as 1882 when I had a controversy with "The Australasian" newspaper on the possibility and the best manner of securing varieties of wheat which would satisfactorily resist rust."*

Thus Farrer himself dates his interest in wheat from 1882, precisely a century ago.

Despite Archer Russell's excellent biography on William James Farrer (published in 1949) I believe the magnitude and the total context of Farrer's contribution and philosophy is not yet fully appreciated.
To understand why he was so enormously influential we need to consider his formative years.

Farrer was born in 1845 near Kendal in Westmorland, in the heart of the English Lakes District. His father and mother came from farming backgrounds. When he was eight his mother died of tuberculosis and he was sent to Christ's Hospital School, then in Newgate Street, London, quite near to St. Pauls. One can surmise that he spent his holidays on his father's farm and that, being intelligent, alert and observant he learnt a great deal about the practices of agriculture. He completed his schooling and proceeded to Cambridge University where in 1868 he obtained First Class Honours in the Mathematical Tripos.

The following year he returned to Cambridge to study Medicine but towards the end of the year discovered that he too had tuberculosis; thus, concern for his health seems to be the basis for his decision to migrate to Australia and to seek an outdoor occupation.

His intention on arrival in 1870 was to take up pastoral land and to this end he gained experience on Duntroon Station near Canberra and appears to have visited many properties in the district. He invested in a mining venture but as this was not successful, he had to modify his plans.

For several years prior to 1875 Farrer worked as an Assistant Surveyor and in that year passed the required examinations and became fully licensed. He was then engaged under contract by the Lands Department of N..S.W. to conduct surveys in the Dubbo District, a growing agricultural and pastoral centre on the new main western railway some 400 kilometres from Sydney.

All the while he was observing and thinking about the problems and of the prospects for enhanced agricultural production in the region. From the moment Farrer set foot on this continent he, even when he no longer aspired to become a pastoralist, was devoted, heart and mind, to things pertaining to the land. Evidence for this is provided in 1873 in the form of a pamphlet with the title

"Grass and sheep farming a Paper Speculative and Suggestive"

By William Farrer B.A.

In this pamphlet he comments in connection with agricultural education :

"It remains of course, to be seen how long it will be before technical education becomes properly treated in the colony" ... "America has colleges in almost every state in which not only agricultural chemistry and scientific agriculture are taught, but at many of her colleges practical instruction is also given ..." "In this way America has made large strides since the Civil War. This (type of) institution is largely supported by the Government but out here (in Australia) a morbid, overstrained, and generally misdirected policy of economy seems to be paralysing all true progress."

Roseworthy Agricultural College, Australia's first institution concerned with Tertiary Education in Agriculture was established in 1883, a decade after Farrer's statement of urgency.

Farrer also commented that:

"if science had any function at all, it was in relation to husbandry - the production of the primary human needs."

In the same pamphlet, which he described as theoretical, he advanced the view:

"Those who affect to despise theory will do well to recollect that a function of theory is to examine the foundations of practice and by this means to modify it and extend it advantageously."

Prior to Farrer's involvement, the Australian Wheat Industry was expanding particularly in South Australia. In 1880, of the total area of 3 million acres sown to wheat in Australia, 1.7 million or almost 60% was sown in South Australia with only 8% sown in N.S.W.; by contrast South Australia now provides about 10% of Australia's wheat crop with New South Wales and Western Australia being the leading producers.

Forty years before Farrer, around 1850, Mr. John Frame, at Mt. Barker some 30 kms from Adelaide had selected a wheat which he called Purple Straw - this was probably a selection from an Italian Wheat called Tuscan which had come to Australia via Scotland. This selection was the principal wheat grown between 1860 and 1890 and permitted the expansion of the wheat belt from areas around Gawler and Angaston to Strathalbyn and Yankalilla in S.A. to the extensive plains north of Adelaide, and to the Wimmera and Mallee areas in S.A. and Victoria.

It should be recorded that Purple Straw was one of two key wheats in the ancestry of most of the Australian wheats up to Halberd in the late 1960's when Albert Pugsley was instrumental in introducing Mexican dwarf material from the International Centre for Wheat and Maize Improvement in Mexico: these cultivars or varieties being the basis for the "Green Revolution" with respect to wheat.

Purple Straw had its influence through Farrer;s principal variety, "Federation" and probably through Marshall's No. 3.

Richard Marshall, a farmer at Wasleys a short distance north of Adelaide, made some 90 selections, the outstanding of which was "Marshall's No. 3" released in 1890; this selection probably arose from natural outcrossing or chance hybridisation between "Purple Straw" and "Wards Prolific" which was a selection by James Ward, a Port Pirie farmer, from a South African wheat "du Toit" imported by Dr. Richard Schomburgh, then the Director of the Botanic Gardens in Adelaide.

One needs to stress that various wheats imported to Australia were not pure or fixed lines and when they were sown, a mixed population of plants containing many different types was evident; the plants with the best developed heads and with other desirable characteristics including rust resistance were chosen and multiplied to obtain seed for growers. This was the method used by Frame, Marshall, Ward and others.

This method contrasts with the crossing or breeding approach which involves the selection of parents with desirable characteristics, crossing these wheats and then choosing the most favourable plants from the progeny.

The selected progeny are then taken through 4 to 8 generations in order to fix the variety or genotype. Farrer was the international pioneer or this scientific approach.

In a paper written early in this century by Biffen the pioneer Wheat breeder in Britain and Professor of Agriculture at Cambridge, we read that:

"... *With a foresight which seems almost uncanny Farrer chose the best forms to use for intercrossing, cut his way through all the difficulties of obtaining fixed hybrids and gave Australia a series of wheats far more suitable for the conditions than any she had grown previously. Farrer, working almost to his last year with no knowledge of the modern subject of genetics, anticipated and even solved, so far as Australia is concerned, some of the most*

On the subject of Mendelian genetics Farrer in 1905 wrote to Professor Biffen in the following terms:

> *"In your letter you speak of the old bugbear of fixing varieties. This work for the last twelve or fourteen years has given me no trouble whatever. It seems to me, from what I see of Mendel's theory of heredity, that the consideration that I then gave to the matter of fixing varieties, led me to accept the system which, for all practical purposes, Mendel's theory indicates as being the best ... I certainly had not Mendel's theory to go on".*

But, Charles Darwin's ideas seem to have influenced Farrer tremendously in his revolutionary methods in the selection of parents for the cross-breeding of wheats: one of the books Farrer most highly valued was Darwin's

"The Variation of Plants and Animals under Domestication"

When Farrer resigned from the N.S.W. Department of Lands in 1886, it was to take up the important work of breeding wheat on 3 acres of land on the banks of the Murrumbigee River on his property Lambrigg, about 20 miles from Canberra.

For at least 3 years prior to this, and for the rest of his life, Farrer was an energetic correspondent and collector of "Varieties" from some twenty countries and had given and sought much advice in his dealings with Vilmorin in France, Blount in Colorado, Carleton in Washington, Pye at Longerenong Argricultural College in Victoria and Lowrie at Roseworthy. So Lambrigg became a living laboratory and Farrer's correspondence its body of literature.

Between 1898 and his death in 1906 Farrer was employed by the N.S.W. Department of Mines and Agriculture.

His career achievements can be summarised:

He introduced hybridization procedures and a systematic methodology in breeding wheats which were early maturing, better adapted to water and heat stress conditions of our environment and disease resistant especially with respect to rust and also to bunt.

In addition his association with the cereal chemist Guthrie gave rise to better milling and baking wheats.

PART II

In his letter of August 1898 to the Under-Secretary of Mines and Agriculture in N.S.W. accepting the post of Wheat Experimentalist, Farrer set out his manifesto. In this letter he refers to the importance of soil management, thus:

> *"In addition to improvements in the wheat plant itself, it is, I consider of even greater importance that I should conduct experiments for the purpose of ascertaining the methods of soil-management which are the most suitable for our climate and the conditions under which our wheat growers are working. It has long been my conviction that the system of alternate cropping and fallowing which is being followed so generally by wheat farmers of Australia is a mistaken one; the present impoverished condition of the once famous wheat lands of South Australia, whence the system originated and has been in operation so long, supports this "opinion"."*

It seems therefore that it would be fitting if I were to speak this evening of some of the factors which determine the best management strategies suitable for the red-brown soils which occur in all States throughout the Australian Wheat Belt. The same basic principles are appropriate, in modified forms, to the management of the extensive sandplain country in W.A., the calcareous soils on the West Coast of South Australia, the Mallee soils in both S.A. and Victoria and also to an extent to the heavier textured soils of northern N.S.W. and Queensland where wheat is grown using summer rainfall stored in the soil profile.

The ideal of the farmer is to attain a stable system of management based on the use of seasons under grass-subterranean clover to improve soil fertility by raising soil nitrogen levels and by improving the physical stability of the surface soil. Both effects generally enhance the yield of subsequent cereal crops.

According to Professor C.M. Donald the progress of wheat production in Australia can conveniently be divided into three main phases.

(i) First, the decline in yield between 1870 and 1900 because of the depletion of nitrogen and phosphorus and continuous cropping and fallow. The decline to almost half the 1870 yields was also a reflection of the expansion of cropping into climatically less suitable areas.

(ii) Secondly, with the introduction of superphosphate early in the century and the improved varieties flowing from the work of Farrer and those who followed him, yields rose but even so did not attain the 1870 level again until 1950. The nitrogen deficiency was partially met, not by the use of fertilizer but by the adoption of an ancient technique for the more rapid exploitation of the soil by a fallow year which was used to conserve water for the following crop year.
However, nitrogen was also released during the fallow period by the breakdown of soil organic matter.

The poor physical condition of the soil resulting from this practice was the cause of extensive wind and water erosion of Australian wheat soils between the two world wars.

(iii) Thirdly, after 1950 when the extensive use of fertilized Wimmera rye gras subterranean clover became common practice, there was a very significant increase in the levels of organic matter and hence soil nitrogen and physical stability of soil aggregates.

Farrer had clearly perceived that the impact of improved varieties would be limited by physical and nutritional circumstances unless equivalent attention was devoted to management strategies which would sustain soil fertility.

Agricultural Scientists must ask the following questions concerning the present yield plateau:

(i) Will the current increase in the area sown to crops on farms lead to decreased yields, despite the introduction of new improved varieties?

(ii) What rotation is the most appropriate to sustain soil fertility?

(iii) What priorities for scientific research should be established to enable cereal breeders to lift yields to a new plateau given that soil fertility can be sustained?

Today we have a remarkably detailed knowledge of the biochemical and physiological events involved in symbiotic nitrogen fixation in terms of the host-Rhizobium relationship and also the circumstances pertaining to effective nodulation. We also have a good knowledge of the nature of soil organic matter and the processes involved in its breakdown.

However we are very much less well informed about the quantitative aspects of nitrogen fixation by subterranean clover and medics in pastures. Estimates vary from 20 to 200 kg. of nitrogen per hectare per annum, this variation being occasioned by variation in season, nodulation, level of nutrients particularly available phosphate and grazing management. In general, however, the amount of fixation is related to total dry matter production.

There are, in these energy conscious times, very real advantages in fixing nitrogen naturally in the field, and perhaps the foremost is that in the Haber-Bosch process high pressures and temperatures have to be used to obtain ammonia. As a result the equivalent of the energy from 7 tonnes of coal is required to produce 1 tonne of ammonium sulphate.

Carter, on the assumption that 70 kg. of nitrogen is fixed per hectare per annum, calculates the value of nitrogen fixed by pastures at $1500 million; if one allows for the animal production sustained by these pastures another $1000 million is gained making a total yearly contribution to Australia's agriculture of $2,500 million.

The organic matter accumulated during the pasture phase of a rotation is mineralised during the growth of a crop, and the rough rule of thumb is that each year 3 to 5% of the total organic nitrogen in the soil forms nitrate ions which are available to the growing wheat plant. Thus in the pasture phase the soil nitrogen must be lifted to a level which allows an adequate nitrogen supply for two or three wheat crops, bearing in mind that a crop of 1.3 tonnes per hectare (20 bushels per acre) contains 30 kg. of nitrogen in the grain and a further 14 kg. in the stubble.

The experience accumulated in the 1950-1960's period which I have already referred to, provides the basis for a stable eco-system. During these years common practice was for as much as three years of pasture to one year of crop, a ratio of 3:1; whereas now a common rotation may be three years of pasture and three years of crop; that is a ratio of 1:1. There is a growing tendency to crop more frequently than this.

We must realise however that market forces drive the system because in the 1950-1960 period the price of wool relative to grain was high whereas at the present time the relatively high price of grain has caused rotations to narrow appreciably, so that cropping tends to predominate with a consequent decrease in physical fertility and hence yields. Yields might also be expected to decline because the price of superphosphate has resulted in much smaller amounts being used on pastures. When present soil phosphate reserves fall then nitrogen entering the soil organic fraction will decrease. Thus pasture production and carrying capacity for animals will decline as well as wheat yields. The stable eco-system of the 1950 to 1960's period will have been significantly disturbed.

The cost of fertilizers is of great importance to wheat growers in the nineteen eighties. This can be underlined by an examination of movements, during the last decade, in the prices of fertilizers to farmers and the returns they receive for their grain. Since 1972, the price to farmers of nitrogenous fertilizers has risen by a factor of 8, from $21 to $173 per tonne and the price of superphosphate has increased by a factor of 7. The payment to farmers for bulk wheat during the same period has increased by a factor of only 3, from $50 to $146 per tonne.

With increases in other costs for example fuel, one can readily appreciate the farmers concern for declining terms of trade which is otherwise known as the cost-price squeeze. As a consequence the Australian farmer is continually being forced to be more cost efficient and this must be achieved by increased production.

Physical Fertility

The seed bed created in a red-brown earth soil by conventional cultivation practices can, depending on the proportion of pasture to cropping in previous years,react differently to the varying amounts of rainfall and especially its intensity during the month after sowing.

Experience has shown that where wheat is sown into land which has been under pasture for say three years, heavy rain shortly after sowing has no adverse effect on the stability of the soil aggregates nor on plant establishment.

However similar rain on a fallow-wheat rotation results in the soil aggregates breaking down leading to compacted soil structure with a reduced permeability. Other consequences are, of course, run off, loss of water and rill erosion.

The final judgment in such matters must be based on yield of the crop. As a result of measurements of soil structure and yields over a number of years on different rotation plots R.J. Millington has arrived at the paradoxical relationship that yields on a red-brown earth soil at the Waite Institute decreased by 0.4 tonnes per hectare or by 20% for each inch of rain in the month following sowing on soils with narrow rotations.

These results emphasise not only the importance of physical fertility but the extremely complex interaction between rainfall, rainfall intensity and plant performance.

Erosion is a serious problem which is exacerbated by narrow rotations. Let us consider the profile of a red-brown earth soil which has a marked contrast between the loam A horizon and the red clay B horizon at about 30 cm. The depth of the profile to the loam horizon would be about 100 cm. Radio-carbon dating would tell us that a profile takes about 50,000 years to form. Thus, it takes 1000 years to form 2cm of soil.

One centimetre of soil spread over a hectare can be readily calculated to weigh 125 tonnes. For red-brown earth soils in a rolling terrain the Victorian Ministry of Conservation considers the average soil loss is at least 2 tonnes per hectare per annum and as the grain yield might also be two tonnes per hectare; we are trading grain for soil.

On the above calculations soil is being formed at the rate of one-quarter of a tonne over an area of a hectare per year. We cannot therefore claim that agriculture is a renewable resource when erosion exceeds the rate of soil formation.

According to the C.S.I.R.O. publication ECOS the defined tolerance for erosion widely accepted in northern N.S.W. and Queensland is 12.5 tonnes per hectare per annum.

Erosion is an exceedingly serious problem which must be addressed more vigorously by governments and scientific bodies.

We are therefore vitally concerned with the stability of aggregates, a subject my research students and I have been especially interested in. We have found that for pastures up to four years old ~~that~~ the poly-saccharide-polyuronide fraction of the soil organic matter is especially beneficial in promoting aggregation. In chemical terminology these compounds belong to the group of substances called gums. Thus we must have appropriate rotation practices to keep the soil particles gummed together; this effect is enhanced by the network of fungal hyphae ramifying through the soil.

The answers to some of the questions I have raised are to be found in the field of soil biology and plant pathology.

The bacterial population in a fertile soil is estimated to be 1,000 million per ounce (one teaspoon full) of soil and the length of fungal hyphae in the same amount of fertile soil is estimated to be about 1000 metres. This biomass, whilst occupying less than 1% of the volume of the soil has a powerful influence in view of the many functions performed by soil organisms such as nitrogen fixation and the decomposition of organic matter to release nutrients.

This galaxy of organisms exists in the presence of plant roots, and it is noteworthy that, during the growth of a wheat crop, as much as 1 tonne per hectare of the carbon fixed by photosynthesis may appear in the soil as substrate or food for soil micro-organisms. The "rhizosphere" is thus a zone of intense micro biological activity.

Lewis and I have examined the physical nature of the root soil interface and have been able to present a mathematical analysis of the diffusion of phosphate ions to plant roots. The diffusion is radial to the root hairs and as indicated by Einstein's root mean square displacement is operative over distances of about 0.2 mm. There are about 60 root hairs per millimetre of main root and their distance of separation is about 0.1mm. These studies have implications for availability of other nutrients and fertility assessment by routine chemical methods.

Some organisms are not beneficial but are pathogens which cause lesions in plant roots which gives rise to loss of efficiency and hence loss of production.

For example, it is estimated that cereal yields in Southern Australia especially of what, are depressed by as much as 30% by the Cereal Cyst Nematodes and Take-All (or Hay-Die) Fungus. Cereal nematodes or eelworms are known ot decrease production by 70 million dollars annually in South Australia and Victoria, and an unknown and possibly increasing amount elsewhere in Australia.

It may take as long as 20 years before pupulations become sufficiently great elsewhere to reduce yields significantly. The presence of the cereal eelworm has recently been reported as far away as Tamworth in Northern New South Wales.

As a result of studies by Fisher of the Waite Institute, and Dube of the S.A. Department of Agriculture, it is now possible to control the nematode. It is unlikely that the nematode will ever be eradicated but it can be controlled by management techniques which include the use of resistant varieties and the rotation of crops.

In the presence of a resistant variety, the eelworm is unable to multiply at the same rate so there is a reduction in the carry over of eggs into the following season. Plant tolerance measures the ability of a variety to continue to peform well despite damage caused to the roots by the cysts of the organism.

Wheat and barley cultivars with both resistance and tolerance have been or will shortly be released by wheat and barley breeders. This extremely satisfactory state of affairs results from nearly a quarter of a century's research.

The position with Take-All is more complex as, in the vicinity of the root lesions, organisms other than *Gaeumannomyces graminis* are present. These include species of *Helminthosporium, Fusarium and Phythium.* It seems possible that in some environments these other organisms may be the principal pathogen rather than the secondary infection. In general, however, principal component analysis identifies Take-All as the main pathogen. Rathjen has been able to obtain some degree of resistance in some cultivars while some recent studies of Graham and Rovira suggest that the disease is less serious where manganese levels are adequate. Also the prevalence of the disease Hay-Die on wheat grown on calcareous soils on the West Coast of South Australia may be explained as arising from a sub-clinical manganese deficiency on those soils with a high pH. This observation underlines the possibility that complex environmental relationships of the pathogen itself may be involved.

If resistance cannot be obtained from the existing germplasm available to the wheat breeder, then it might be possible to secure the resistance or other desirable characters from one of the many species related to wheat. Cyto-geneticists have the capacity to manipulate the chromosome content of plants - a process that Sears has called Chromosome engineering. Such manipulation of the plant nucleus has such profound implications that we are justified in speaking about The New Nuclear Age.

The genetic variability of cultivated wheats, accumulated over 10,000 years of cultivation, has now been diminished by the modern scientifically planned breeding practices.

Bread wheat, *Triticum aestivum*, contains three sets of chromosomes designated as A, B and D which arise from three wild species. Both field and archaeological evidence has revealed that *Triticum aestivum* probably arose from a spontaneous hybridization between *Triticum turgidum dicoccum* and *Triticum tauschii* in a farmer's field somewhere in Western Iran about 8,000 years ago.

Thus crosses between species can provide a means of increasing the gene pool. The first exploitation of an interspecific cross was by Muntzing in Sweden who crossed wheat and rye to produce a new cereal which combines the hardiness of rye with the quality of wheat. Several people at the Waite Institute have successfully crossed wheat and barley. This has significance in that it shows that wheat and barley have a common heritage, and as they belong to different sub-tribes of the *Triticeae* it indicates that chromosome material from all 14 genera are potentially available as a source of alien germplasm for incorporation into the wheat nucleus or genome.

Some examples can be provided to indicate the promise of this approach:

(1) The wheat-barley hybrid is not in itself important but the chromosome material which can be recovered from this cross and added to wheat as foreign germ plasm will enable a wider base for disease resistance and salt tolerance to be achieved. As an instance in California, using the Waite material, an attempt is being made to transfer barley yellow dwarf virus resistance from barley to wheat. By cyto-genetic techniques, substitution and addition, lines can be achieved in which a wheat cultivar has two chromosomes added or replaced in its normal complement of 21 pairs.

(11) Another successful example is provided by Graham, who by the addition to wheat of one arm of the 5R rye chromosome has been able to develop in the wheat a capacity to grow and to produce seed under conditions of low copper in the soil. Previously the wheat cultivar was only able to set seed on such copper deficient soils when copper-sulphate was used as a fertilizer.

(111) A third example is that in Canada part of the chromosome material of *Agropyron elongatum*, a wild grass related to wheat, was transferred to wheat. This is believed to involve less than one half of a chromosome but has given rise in the wheat variety Kite, bred by Pugsley and Martin, a cultivar ~~which has~~ with a unique basis for rust resistance which is still fully effective in Australia after 10 years.

The profound significance of this new field of endeavour is that it provides us with the opportunity to re-trace some of the natural evolutionary processes which by a degree of chance have given rise to the materials from which our modern bread wheat is derived.

It is my belief that the most important impediment to attaining in the future a new higher plateau in wheat yields lies in solving the problems associated with root diseases and one hopes that resistance may be achieved by chromosome engineering from one of the vast number of species in the Gramineae or grass family.

The quantum jump we are seeking in yields may arise more naturally as our body of scientific knowledge, especially in genetics, plant pathology, plant nutrition, plant physiology and plant biochemistry finds its expression in breeding programmes.

IN THIS ADDRESS I have tried to emphasise, following Farrer's example, that we can no longer look at problems concerning wheat production as single isolated events. Whatever disturbance occurs or whatever we do to correct that disturbance involves complex biological inter-relationships for the whole system and creates perturbations which in the long term may have unexpected and disproportionate effects on the system.

Zerlerate Karks