The 1965 Farrer Memorial Oration

Water, Agricultural Production and World Population

J. R. A. McMillan,
1965 Farrer Medallist

William James Farrer became concerned in two main aspects of wheat production. These were the loss of crops through disease and through lack of water. Farrer set out to try to overcome these problems through breeding of more suitable varieties, and he achieved great success in both fields.

Rust was the worst disease which he attacked and he ultimately produced varieties less liable to succumb. It is, however, very difficult to estimate the improvement he effected because of the ever-changing rust flora. We know now of the existence of many races of the rust organism and the fact that new ones are being produced frequently. The result of this is that present-day plant breeders find that a newly produced rust resistant variety lasts for only a few years and then it becomes susceptible. Perhaps Farrer achieved the same success in his day.

Farrer's great contribution to water efficiency was to produce varieties which matured earlier and so escaped the dry period in the summer when the older varieties were ripening. In this way he was able also to push the wheat belt inland to drier areas.

Introduction

I have chosen water, agricultural production and world population as my topic because I believe that water is the most important factor limiting agricultural production and because I believe insufficient attention is being paid to it. It is true that much more thought has been given to it in recent years and the recent drought in parts of Australia, especially New South Wales, has emphasised it.

The world's requirements of fresh water for agricultural, industrial and domestic purposes are increasing very rapidly—at least as fast as the increase in population. Many countries which not long ago appeared to have very much more water than they expected they would require, are now facing the prospect of a water shortage in the next decade or so. The U.S.A. is an example of such a country and now much investigation is under way to determine how the situation can be met.

Water will become even more critical as the world's population increases and more food is required. It is expected that the world's population will double from its present 3,000 million to 6,000 million before the end of this century and of course to

". . . I believe that water is the most important factor limiting agricultural production and . . .

Readers will realise that this oration is far longer than the articles usually published in the Gazette. *We are confident they will agree that the importance of Professor McMillan's theme, and his very readable presentation, more than justify publication of the complete text here.*

The full text of this oration was first published in the October, 1965, *issue of the* Australian Journal of Science.

—Editor

Professor McMillan

provide the same quantity of food per person food production must be doubled. But many people are underfed and starving and to feed the population adequately probably four times the present food production will be required. And this of course means much more fresh water being available for Agriculture and much more efficient use of water.

I do not in this address propose to refer to or to discuss water conservation as such. I am assuming that everything that can be done will be undertaken in this direction—that as much as possible of all surplus water in any area will be stored and used effectively. I will concentrate on other aspects of the problem and examine, briefly in many cases, such matters as:

(*a*) The quantity of water required for the production of different agricultural products;

(*b*) the quantity of water required for Agriculture as compared with that required for industrial and domestic purposes;

(*c*) increasing the efficiency of water use in Agriculture by (i) improved agricultural techniques and (ii) breeding more efficient plants;

(*d*) additional sources of water; and

(*e*) the potential world population based on rainfall.

Quantities of water required for agricultural production

The enormous quantities of rain which are required for the production of agricultural products are generally not appreciated. But it is vitally important that these be recognised so that people may have a better appreciation of the significance of water.

To assess the quantities required, one must take into account the water used by the crop by transpiration throughout its growth and also losses from the soil by evaporation. In the case of animals one must assess the amount of water required to produce the crops for the feed for the animal. If a product such as milk is being

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considered one must take into account the feed required to grow the animal until it is in milk and also for the dry period between lactations. A similar situation holds for egg production, because the hen has to be raised to "point-of-lay" and if it is kept for a second year it has to be fed during the period of moulting.

Generally, quantities of water required for crop and animal production are given as inches of rain per acre. I do not think that this gives a good idea and I prefer to express it in tons or gallons of water per unit of produce.

The average quantities of rain required for some Australian products are:

	tons	or gallons
1 loaf of bread (2 lb.) ..	2½	560
1 egg	1	220
1 gallon of milk	15	3,300
1 pound of scoured wool (in a good rainfall area)	250	56,000
1 pound of scoured wool (in a poor rainfall area)	750	168,000
1 man's woollen suit	1,000	224,000
1 orange	½	110
1 3-lb. chicken	15	3,300
1 pound meat	50	11,200
1 pint of beer	1½	330

It is interesting to estimate the quantity of water required per day to provide the food for one adult and give him a normal Australian diet of about 2,700 calories. This would be 35 tons of rain per day. Taking into consideration the population as a whole, that is men, women and children of all ages, the average daily calory requirement is 2,000. The average quantity of water required to produce this food for each person in the community is 26 tons per day.

This figure of 26 tons of water for the food for one person per day might well be compared with that for industrial and domestic requirements. A basis for comparison is the use of water by the M.W.S. & D. Board in Sydney. While some of this is used for agricultural production and some of the secondary industry products would not be used by the people in Sydney supplied with the water, this is not material to the point to be made. The average annual consumption of water in Sydney is 93,000 million gallons and the population the Water Board serves is 2.6 million. Thus the average water requirement per person per day for industrial and domestic purposes is less than 0.5 tons and this is only 2 per cent of that required for food. If one considers also the water used for agriculture or forestry for the production of clothing and shelter the difference between agricultural requirements on the one hand and industrial and domestic on the other is so great that the requirements for industrial and domestic purposes appear negligible.

Sources of water

There is of course no significant variation in the quantity of water on Earth. It is not made nor destroyed but is used over and over again. The water cycle starting with clouds is rain, evaporation and clouds again or rain through plant and/or animals and back to clouds. It may be used several times as water before going back to clouds.

To emphasise this in a country where a shortage of water is arising one writer referring to the use of water along rivers stated that people would soon be using their own bath water. This is not new—we are in fact drinking one another's bath water now. Certainly it is purified by evaporation.

It would be very interesting indeed to follow the history of a molecule of water. Starting as rain it may fall on the soil, be absorbed by a plant, eaten by an animal, passed on to a human being, perhaps from one human being to another by various means, then to some river and flow a thousand miles, be evaporated from the sea, carried thousands of miles in air currents and deposited as rain on a totally different part of the earth and start another cycle. At one time it may be in the sea, at another in a fish, or a plant, be ice, be in some chemical, and so on.

Since the total water on the earth cannot be increased and we require more agricultural production we must increase the efficiency of water use or obtain more fresh water per annum or do both.

Farrer Medallist for 1965, Professor J. R. A. McMillan, D.Sc.Agr., M.Sc. (Cornell), Professor of Agriculture, University of Sydney, delivered the Farrer Memorial Oration during a Special session of the 38th ANZAAS Congress in Hobart on 19th August, 1965.

Chairman of the Farrer Memorial Trust, Dr Grahame Edgar, New South Wales Director-General of Agriculture, presented the Farrer Memorial Medal to Professor McMillan during the function.

The medal is an annual award by the Trust for outstanding service to Australian agriculture, and it commemorates the work of Australia's pioneer wheat breeder, William James Farrer.

Professor McMillan is an outstanding scientist in the general field of agriculture.

He has displayed a particular interest in the application of science to agriculture and the solution of practical problems of agricultural production, as well as in the advancement of tertiary education in Agriculture.

Biographical

Professor McMillan graduated B.Sc.Agr. from Sydney University, with First Class Honours and the University Medal, in 1924; M.Sc. Cornell University, USA, in 1925, and D.Sc.Agr from Sydney University in 1937.

He was awarded the Sir Ben. Fuller Travelling Scholarship to the USA in 1924-5 to study genetics, plant breeding and cotton production.

In 1926-9 he was plant breeder at the Agricultural College in Gatton, Queensland, where he commenced the then modern hybrid maize breeding programme.

In 1927-9 he was lecturer at the University of Queensland, and from 1929 to 1946 he was Senior and later Principal Plant Geneticist with CSIRO in Canberra, working on genetics of wheat and pastoral plants.

He was seconded in 1942-6 to the Commonwealth Department of Commerce and Agriculture to be in charge of vegetable seed supply and production during the war.

Professor McMillan was appointed Dean of Agriculture and Professor of Agriculture at the University of Sydney in 1947. He was a member of the University Senate 1947-52 and 1964-5.

He has studied agricultural problems in North America, Europe and Asia and his publications include research and reports on genetics, plant breeding and agriculture generally.

He has represented Australia at international conferences—for example, the FAO 1949 and the United Food Congress in 1963. He was Honorary General Treasurer of ANZAAS from 1946-52 and has been Honorary General Secretary since 1952. He is a Past President and Honorary Life Member of the Royal Society of Australia. He is also a Past President of AIAS.

Professor McMillan is a member of various committees associated with agricultural development, and is National Vice-President and State Chairman of the Freedom From Hunger Campaign.

Rainfall and crop production

The effect of different quantities of water on crop production is well illustrated by simply comparing production in a good rainfall year with that of a year when it is poor. The yield in a good year is often much higher and may be several hundred per cent more than that in a poor year and yet the difference in rainfall may not be very great. Often an increase of only 20 to 30 per cent in rainfall will double or treble the yield.

Even in so-called good rainfall years there are very often temporary water shortages and the plants are subjected to stress with a consequent reduction in growth and yield. This even occurs in countries which are usually regarded as having a good rainfall, for example England and Sweden.

Much of this trouble arises from the fact that plants use the available water too quickly and so deplete the store in the soil. As this happens the growth rate is slowed down and if the soil becomes too dry growth stops. The plants then remain dormant until rain falls or they may die. As soon as rain comes the survivors start growing again (if other conditions are suitable). This is very obvious in pastures and perennial crops which may remain dormant throughout a long dry season.

Rain which falls on a farm may be lost from the soil by surface run-off or drainage; or it may be stored in the soil, in which case it is ultimately lost by evaporation, transpired through weeds or used by the crop. The run-off and drainage water may be stored and used later for irrigation.

If we are to become more efficient in water use with the crops and varieties which we have we must increase to a maximum the water holding capacity of the soil; get as much rain into the soil as it is capable of holding, reduce evaporation to a minimum and reduce transpiration through weeds to a minimum. These requirements apply to a period before the crop is sown or planted as well as during its growth. The proportion of water lost by evaporation and weed transpiration may be up to 70 to 85 per cent.

The necessity of making careful use of the available water in limited rainfall areas has been recognised for some thousands of years. This has mainly taken the form of storage and later irrigation. However, associated with this, an interesting practice was developed in Ceylon over 2,000 years ago. Run-off water is stored in dams during the rainy season and later is used for rice production. Having stored the water the people estimate the area that can be sown to rice and then plant accordingly. An effective system of land control and occupancy has been devised to obtain the most efficient use of the water and to ensure the maximum crop.

A modern modification of this is the water harvesting scheme devised by H. J. Geddes. Under this a part of a farm is developed primarily as a catchment area and crop production is concentrated on the remainder, which may be only 25 per cent of the farm. When rainfall is limiting, more efficient use of the water as a whole is obtained by this method.

Instead of storing water in dams, experiments are under way to ascertain if it is feasible to concentrate the water in a portion of the soil, for example by bench cultivation. This is being tried in the U.S.A. on sloping land. On a section of the slope the lower portion is levelled, or the slope is greately reduced to provide a "bench". Rain falling on the upper portion is allowed to run off on the bench, thus concentrating it there. Then crop production is undertaken on the bench with the increased water.

As would be expected, the use plants make of fertilizers is largely dependent upon the water supply available, and, of course, in many areas the quantity of water in the soil at sowing time is important in this connection. Work over the past few years in the north-west of New South Wales has shown that it is desirable to base the fertilizer application for wheat crops on the soil moisture content at sowing. This applies particularly to fertilizers which may be leached from the soil.

Although a bare fallow to increase the soil water content is often adopted a large proportion of that which enters the soil may be lost by evaporation before the crop is sown. For example, in north-western New South Wales wheat is grown in the winter and spring, while the rainfall is mainly summer. In the fallow period the equivalent of 8 inches of rain may have been incorporated in the soil. However, in spite of adopting all known economic methods of conservation of water in the soil, by the time the crop is sown a few months later, this may be reduced by evaporation to the equivalent of 2 inches—a loss of 75 per cent.

Much research has been done over a long period of years to find ways of reducing losses by evaporation. This has been directed mainly to (*a*) interfering with the rise of water to the surface of the soil and (*b*) by placing something on the surface to reduce evaporation—usually mulches.

More recent work has been concerned with attempts to treat the surface soil in such a way, that while it does not interfere with the entry of water it retards and reduces very greatly the evaporation of the water from the soil. Chemicals which may be sprayed on to the soil are being tried.

In some cases these result in semi-permeability. But other chemicals are impermeable and these are being applied in narrow bands. Rain water may enter the soil between the bands and the bands greatly reduce evaporation.

The use of bitumen emulsion has already proved successful. And now various plastics are being tried.

Anything which proved successful would not only have to be economic, but it must not damage the soil permanently if it is to be used commercially.

It is well known that a soil covered by stones or with a large proportion of the surface covered by stones loses less water by evaporation and very good crops can be obtained from it. One wonders whether it is possible to treat the soil in some way so that the surface could be converted to flakes like saucers which would be impermeable to water.

The development of weedicides, especially selective weedicides, during the last 25 years has given us much better control over weeds and the consequent losses of water. It is expected that there will be much further improvement in this.

Most efficient use of water

The factors which affect growth and production, besides water, include light, temperature, soil fertility—chemical, physical and biological—weeds, diseases, insect pests, varieties of crops, strains of animals and the whole technique of production or management.

Any one of these can be limiting and so prevent or retard the maximum growth and yield. Hence for the best results each has to be optimal; for example any soil deficiency must be overcome, weeds, insect pests and diseases must be controlled; one must use the best variety or strain of animal and the whole operation must be managed most efficiently. If this is done then there will be much greater production per unit of water used and thus an increase in the efficientcy of water use.

It was pointed out earlier that under average conditions in Australia 15 tons of water are required to produce 1 gallon of milk. However, using Geddes' water harvesting scheme and Crofts' selection of species, and use of fertilizer in relation to time of year, the quantity of water required per gallon of milk can be reduced to half of the above.

Similarly for wool production (without irrigation), if improved pastures are used, fertilized properly and managed efficiently, the quantity of rain per pound of scoured wool may be of the order of 50 tons instead of 250 tons.

An interesting comparison is available from rice production in different countries. This is as follows:

Country	lb of water per lb of rice produced
Thailand	10,000
India	10,000
Japan	4,900
U.S.A. (California)	3,300
Australia	2,900

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Some of these differences may be due to climatic conditions, but the greater part would be due to efficiency in production. There would appear to be no reason agriculturally why Thailand and India should not be as efficient as Japan.

It is well known that in irrigation areas often much more water is applied to the land than is necessary to produce a maximum return. The extra water is wasted and in some cases results in the destruction of the soil through salting. We have had this trouble in our own irrigation areas—particularly the M.I.A.—and in West Pakistan it is reported that 100,000 acres are being lost per year from salting.

However, the more important point here is whether, in the interests of overall agricultural production, it would be better to spread the available irrigation water over a wider area. For example, supposing 100 units of water are required to get the maximum production, it might be possible to get a yield of say 80 per cent of the maximum for only 50 units of water. If other suitable land is available then it might be better to spread the water over a larger area.

The crop plant and water use

There are two general ways in which the water use efficiency of the plant may be improved.

The first is to treat the surface of the plant with a chemical which will reduce transpiration (use of water by the plant). Some such chemicals are available and are effective but unfortunately they reduce growth and yield as well. However, it is possible that a suitable chemical will be found which does not have unfortunate side effects. This then would be of major importance.

Plant breeding

The second is to breed crop plants which possess greater efficiency, which may result from either (i) improved absorption or (ii) a reduced transpiration ratio.

Improved absorption: Different varieties of plants have different abilities to absorb water from the soil. These differences are due to the root systems which vary in their capacity to penetrate the soil comprehensively and speedily. Such characters may be used in plant breeding.

Reduced transpiration ratios: The transpiration ratio varies considerably between species as shown by Richardson as follows:

Species	Transpiration per unit of dry matter	Transpiration per unit of seed
Peas	344	673
Barley	350	926
Wheat	380	1,088
Oats	390	1,190
Rye	421	1,525

Other species such as lucerne and pumpkin have a transpiration ratio of 1,000:1, while sorghum is as low as 250:1.

The transpiration ratio for the one species will vary under different ecological and environmental conditions. It is one of the main factors which determine the use of different species in different areas.

More important from a plant breeding point of view is the difference between varieties of transpiration ratios. Not so much work has been done on varietal or strain differences, but the following examples will serve to show the possibilities.

Richardson also determined the differences between varieties of the one species as follows:

Species	Variety	Transpiration per unit of dry matter	Transpiration per unit of grain
T. sativum	Yandilla King	209	660
T. sativum	Federation	231	752
T. sativum	Dart's Imperial	227	976
T. durum	Huguenot	243	1,081
T. durum	Kubanka	238	1,188

In another experiment in U.S.A. three strains of Bermuda (couch) grass were tested under comparable conditions and the water used per pound of dry matter produced was as follows:

Strain of Bermuda (couch) grass	lb of water per lb of dry matter
Suwanee	1,105
Coastal	1,431
Common	2,896

Martin 1965 reported results from a similar experiment with wheat varieties. A range of early, mid and late season varieties were grown in large enamel pots in a glasshouse, and grain yield, water usage and other characteristics determined. The results were as follows:

Variety	Type	Grams water per gram grain
Stewart (1023)	early	710
W180	mid	1,460
Mengavi	mid	1,530
Bungulla	mid	2,600
Olympic	late	5,200
Eureka	late	4,500
Hofed	late	3,800

The differences in transpiration ratios may be used in plant breeding. This would require a determination of the extent of such differences between varieties and strains. It would also require an easy and quick way of assessing the transpiration ratio.

However it is almost certain that the differences will not be due to a simple character but be determined by the interaction of several characters. It may then be necessary to identify the major ones and their relative effect. They could be morphological factors but are more likely to be physiological.

Further work by Martin gives some point to this. He reported that the low water usage was partly associated with length of growing season, but largely associated with leaf area at anthesis (flowering)—the larger the leaf area the greater the water usage.

These observations prompted studies on the role of the leaves in grain production, some typical results, with the variety Eureka, being as follows:

Treatment	Grain gram per pot	Grams water per gram grain
Controls	5.5	1,450
All leaves removed at anthesis	5.1	980
All leaves except flag removed at anthesis	6.1	980

This would indicate that leaves after anthesis have no effective influence on yield —in fact they are just wasters of water. Should we not therefore breed a wheat variety on which the leaves die after anthesis?

This might be regarded as mere speculation, but in fact it is not. In 1936 I reported the discovery of a condition of wheat which I called "firing"—it is a form of necrosis. On plants which had this condition the leaves withered rapidly and died shortly after seed setting. The leaves on the plants appeared as if they had been scorched or scalded and hence the term "firing". I found that this was not a diseased condition but a heritable character determined by three pairs of genes. This condition could be easily bred into any variety and so added to other desirable characters.

It is clear however that here there is a vast field awaiting investigation. Because of the importance of the problem and the part that plant breeding can play in solving it this research should be pushed forward with the utmost speed. A great deal of fundamental knowledge is required to determine the factors which control transpiration, to unravel their interaction and to utilise the knowledge in plant breeding.

So complicated is the problem that a large team or teams of scientists should be employed on it. These would include botanists, plant physiologists, biochemists, geneticists, soil scientists, agronomists and plant breeders.

In the past, progress has been slow because of the lack of basic knowledge, but we are now in a much better position to undertake work of this nature because of the great advances which have been made in plant physiology and biochemistry, the use of instrumentation for the assessment of biological processes and our ability to control environmental factors in growth chambers and phytotrons.

Additional fresh water

Two possibilities of obtaining more fresh water are (i) to tap underground reservoirs and (ii) to desalinise salt or highly mineralised water.

Underground water: It is reported that there are great reservoirs of underground water which could be used. But these will have to be used with care. They must be replenished and it would be wise to use only the amount which is added each year. In Australia a strict control over the withdrawal from the Great Artesian Basin has had to be adopted in order not to reduce it too rapidly.

There is no doubt that there are large supplies underground—one writer stating that it could amount to one million cubic miles. If this water were spread equally over the earth's surface it would be 26 feet deep—the sea level would rise from 26 to 40 feet and much land would be submerged. This is another reason why we should not take out more than the intake each year.

Some of this underground water is too high in mineral content for regular use for agricultural purposes. But in Israel two lines of research are being undertaken to find a way to use it. The first is to mix it with fresh water and so dilute the mineral content. However this could not be used permanently because there would be an increase of minerals in the soil so that in a short time crops could not be grown.

The other line of research has two aspects. The first is to determine the crops and varieties which can be grown with water having a high salt content. The second is to devise a hydroponic system of culture to use this highly mineralised water. After a crop is grown it is intended to wash out the increased salt and then grow another crop. A problem with this on a permanent basis is to dispose of the salt, as well as the cost involved.

Desalination of salt water: It seems that in the long run the only way in which we may get enough fresh water will be to desalinise sea water and of course underground water of high mineral content.

A great deal of research has been undertaken to find ways of producing sufficient fresh water quickly and cheap enough. The real problem is of course the large quantities which are required for agriculture. Distillation seems to offer the best possibility and probably nuclear power the best source of energy.

Investigations are under way in countries such as U.S.A. and the U.K. to design nuclear plants for the production of either electricity and fresh water or fresh water alone. If both are produced the water will be cheaper, but so much water will be required that probably we will have to rely on plants producing water only.

R. P. Hammond, 1965, has examined the question of whether nuclear power might be used for desalination to provide water for agriculture. He planned a layout of a giant plant which would produce both electric power and fresh water. Some of the features of this plant would be:

Electric power capacity 17,500 Mwt. which is six times the peak winter demand for all of N.S.W.

Water output of 1,460 million gallons per day or 1,750,000 acre feet per annum, i.e. four times the capacity of Sydney Harbour.

Cost of water 1s. per 1,000 gallons or £12 per acre foot.

Irrigation—440,000 acres at 4 feet per annum. This is twice the present area irrigated in the M.I.A. It could produce enough food for 260,000 people on the basis of the Australian diet. With a minimum diet and with more efficient production this might be 660,000 people.

On the basis of the New South Wales requirement of electricity such a plant should be sufficient for 24,000,000 people, but it would provide sufficient water for about 500,000, that is, only 1/50 of the number. Hence while a dual purpose plant would reduce the cost of water the scope of the arrangement is limited because of the difference in requirements. We must concentrate more on fresh water production and some day we might have to pay the higher price.

The capital cost of this plant would be £260 million and the annual cost including interest would be £20 million.

A number of such stations placed along the seaboard of the world's dry areas could make a useful contribution to agricultural production. But to make a significant impact in relation to the requirements a very large number of plants would be required.

One might speculate that if this were done at suitable places on the Australian coast, the evaporation from the irrigation areas would so increase the moisture content of the air that additional rainfall could be expected in other areas.

The world's potential population based on water supply

Scientists and others have from time to time made forecasts of the world's potential population. These have been based on various factors such as the acreage of agriculture and pastoral land and the potential yield per acre; the energy received from the sun and the ability of green plants to absorb it and so on.

In 1960 Clark stated that if throughout the world agricultural production per acre was equal to that of Holland then there would be enough food with a good proportion of animal products for 28,000 million people, but that if the diet were mainly vegetable then there would be enough for 90,000 million people. While this is an interesting mathematical exercise it is of no significance since it does not consider natural resources in other areas.

Tracey (1964) working on the basis of the plants' ability to synthesise food, the world plant cover, and making allowance for waste, etc., estimated that there would be enough food for from 9,000 to 90,000 million people depending on the number of herbivorous animals left on earth and used for food.

As water is an important factor it is interesting to use it as a basis to estimate the potential world's population. To do this it is necessary to adopt some standard for agricultural products per person. The standard for food should be the minimum required for good health which would average 2,000 calories per day. If we assume an Australian-type diet with a high proportion of animal products the water required per annum would be 9,490 tons per person (based on 26 tons per day—see above). The total world annual rainfall on land outside of the arctic regions according to A. D. Tweedie is 81,000 million acre feet or 81,000 million x 1,200 tons. Therefore on the above basis there should be enough water to provide food for about 10,000 million people. This would apply only if all of the water could be used for food production but this must be reduced for several reasons. First it would not be possible to handle the excess water in the heavy rainfall areas where there is a large run-off. Secondly we cannot use much of the water in areas receiving less than 10 inches of rain per annum. Thirdly there is a large loss by evaporation from unsuitable agricultural areas. Fourthly a considerable quantity of water is required for producing materials for clothing and shelter. Fifthly the impracticability, on the fantastic scale required, of getting the water from areas of surplus rainfall to suitable agricultural areas.

It is clear from this that unless we solve the problem of greatly increasing the availability of fresh water the world population which can be supported on an Australian-type diet is very much less than 10,000 million.

Certainly we could not do this for the estimated world's population of 6,000 million by the end of the century. What then can be done?

An examination of the water requirements for the Australian-type diet referred to shows that 80 per cent of the water used to produce it is required for the meat portion. It is clear therefore that we cannot have such a large proportion of animal produce and that we will have to rely on more vegetable proteins and less animal protein.

From work of N. W. Pirie and his associates this would appear possible. A simple process has been developed for extraction of the protein material from vegetable matter, mainly leaves. This has proved quite satisfactory as a human food and the proteins so obtained will go six or seven times further by feeding directly to

human beings than they would if they were first fed to animals.

Actually this seems to be the only realistic method of supplying adequate proteins to people in the heavily populated underdeveloped countries. Since most leafy material can be used it could be implemented very quickly, whereas the building up of adequate animal populations and providing the feed for them seems impossible.

A wholly vegetarian diet would require only about 1/3 of the water for food production. Therefore on the basis of a wholly vegetarian diet and the annual rainfall of 81,000 million acre feet there would be enough water to provide adequate food for 30,000 million people. However for the reasons given above much of this water could not be used for food production. Unfortunately there is no information on which a reliable estimate could be made. If we could use 25 per cent and this would seem to be a high proportion it would mean a maximum world population of 7,500 million.

Conclusion

If the world's population by the end of this century is to be fed adequately we must:

(*a*) conserve and use for irrigation as much as possible of all surplus water;

(*b*) develop underground sources of supply and use these to the extent that they are replenished annually;

(*c*) become much more efficient in our use of water for crop production;

(*d*) breed varieties of crop plants which are much more efficient in the use of water;

(*e*) desalinise sea water on an enormous scale, probably by using nuclear energy;

(*f*) reduce the use of foods and other agricultural products which have a relatively high water requirement;

(*g*) develop the use of sea foods;

(*h*) develop the use of leaf protein.

This problem of water in agricultural production was recognised over 80 years ago by one of Australia's greatest scientists. He made it part of his life's work to solve this problem as far as wheat was concerned. He had the foresight to realise that the only way to achieve it in wheat was to breed varieties which were more efficient in their use of water. He sacrificed his health and finally his life in his efforts to achieve this. This scientist is the man we honour today—William James Farrer.

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