I am very honoured to have been asked to give this lecture to the Society on our late Fellow, Emeritus Professor E.J. Underwood, OA, CBE, Bsc(Agric)(Hons) WA, PhD (Cantab.), Hon D Rur Sci (NE), Hon DSC (Wis.), Hon DSC (Agric) WA, FRS, FFA, Fh, FAIAAS, FASAP, Hon FACVS, agricultural scientist, teacher, administrator, colleague, and friend.

Eric John Underwood, born in London on 7th September 1905, died a few days before his seventy-fifth birthday on 19th August 1980. He was active right up until that time and, having just sent off the final manuscript of the second edition of his book "The Mineral Nutrition of Livestock", was preparing a paper for a discussion meeting of the Royal Society on the metabolic and physiological consequences of trace element deficiency in animals and man. This he did not quite complete; severe restriction in cardiac blood flow called for remedial surgery from which he did not recover. Four days earlier, as we sat in his office drinking cups of tea - always a delight to him - and after discussing the current work of postgraduate students we jointly supervised, he told me of the diagnosis given him only an hour or so before by his specialist, and that he was going to have the operation with a 50:50 chance of survival, rather than the certainty of invalidity. "I have been lucky in my life time and have had a good spin", he said as we walked quietly down the stairs to the foyer where I had first met him forty-one years earlier and where his portrait now hangs.

Life was not easy for young Underwood but his earnestness and ability earned him firstly a scholarship to Perth Modern School and later a Cadetship of the WA State Department of Agriculture which carried him through the University of Western Australia. Another scholarship enabled him to study the extra year, in 1928, to gain a First Class Honours degree in Agriculture. He was then awarded a Hackett Research Scholarship which took him to Cambridge for three years to read for a PhD, awarded in 1931.

Underwood's nutritional bent and his flair for writing were clearly illustrated in his first publication "An investigation into West Australian Pastures", his Honours thesis, published by the Government Printer in 1929. This work was suggested by Professor J.W. Paterson, Hackett Professor of Agriculture, and supervised by Dr. L.J.H. Teakle, part-time Lecturer, Plant Nutrition Officer of the Department and later Professor of Agriculture in Queensland. The statement "No apology need be made for the subject of this enquiry in a state such as Western Australia, where economic prosperity depends so largely on the productivity of the flocks and herds", introduced this 1929 paper. Referring to comprehensive investigations into the composition of pastures in Great Britain that indicated high mineral content was associated with high nutritive value, the work on low phosphorus in crops and pastures in India and South Africa and the deficiency state known as "bush sickness" in New Zealand, Underwood commented that "... no investigation into the nutritive value of a pasture is complete without an analysis of the constituents of ash". He was to be greatly involved in these topics in a very short time. He went on to examine the chemical composition of samples of pasture he had gathered. Starting in an area north of Geraldton in early September, the herbage being about half ripe to ripe, the author then travelled southwards collecting samples, together with information on previous treatment, type of soil,
botanical composition and on the health and productivity of stock. He commented that, in contrast to British work where ... "in most cases the accumulated experience of centuries was available as a guide to the investigators. In Western Australia the areas are so much larger and the agriculture so much more recent that there is obviously less, and also less reliable, information available". Even so, based on stockmen's opinion of stock performance, "good" pastures on average contained 50 per cent of clover or medic whereas "poor" pastures averaged only 7 per cent; significantly these differences were associated with large differences in the proportions "in which protein and phosphoric acid are present in different pastures"... Dressings of superphosphate increased protein and phosphates in the southern districts.

In Cambridge he started work on milk production in ewes, but his supervisor, Professor T.B. Wood, died and the data of that work were lost; he then undertook further pasture studies with Professor Woodman, experience that sharpened his knowledge and understanding of the interactions of plants, environment and manurial treatments. More importantly, courses in biochemistry and physiology as well as the increased experience in chemical procedures were to be of inestimable value to his subsequent work.

He returned to the WA Department of Agriculture as Animal Nutrition Officer in October 1931 and immediately joined J.F. Filmer who was directing the work on "Denmark wasting disease". In a preliminary report, J.F. Filmer reported on their work which included cures and control of the condition in sheep and cattle with some pure iron salts and iron-containing ores, with raw liver and dried liver from "sound" area animals, but not with the ash of the liver which in any case contained only 0.02 g of iron compared with 25 g in curative limonite ore or 0.6 g in iron ammonium citrate; they then uncovered the anomaly that, despite the anaemia of affected animals and the apparent curative effect of iron compounds, the iron content of liver, spleen, the main haemosderin store, was 0.24, 1.0 and 0.23 per cent respectively whereas normal animals had only 0.04, 0.4 and 0.05 per cent respectively in those tissues. Clearly iron was not deficient, but it was not being utilized. These facts led to the following statement in Filmer's preliminary report on the work the group had so far covered. "The tentative hypothesis is here advanced that enzootic marasmus is due to a deficiency of some mineral necessary for the metabolism of iron; that its deficiency results in functional iron being maintained first at the expense of deficient haemoglobin formation and later at the expense of growth... It is suggested that the hypothetical mineral is commonly found in association with iron, and that the effective doses of iron compounds depend on the proportion in which this mineral is present in available form".

In the earlier part of the work John Filmer's clinical experience and skills in pathology and haemotology had been most valuable in defining the disease; Underwood's chemical, biochemical and experimental skills now become important.

They soon showed that an 0.125 M HCl extracts of 50 g of limonite containing only 35 mg of Fe (compared with 25 g in the limonite) cured affected lambs. They showed further that an iron 'free' extract of this extract containing only 0.2 mg Fe, also cured, but the 32 mg of recovered Fe was no longer effective; indeed a second acid extract of the limonite did not cure either, thus effectively removing iron from consideration. Then the painful fractionation of the limonite 'iron-free' extract began; lack of laboratory equipment and the distance from the Denmark site in those days of severe depression did not help. Separations into the copper, the iron, the zinc, and the sodium groups were undertaken and tested; "... the obtaining of positive
results with more than one group was unexpected". Was there more than one element effective in curing the disease, or was the curative element present in two fractions? Further separations showed the potency was associated properly with the 'zinc' group. A nickel fraction and a nickel-free group were separated but the animals treated with them all died; however a dose of 2 mg of nickel from nickel oxide, but not 2 mg nickel from nickel chloride, was effective. Clearly, then, neither zinc nor nickel were the unknown element which had to be an active contaminant of the Ni in extremely minute quantities; It was decided to include manganese and cobalt "... although these could be present in the 'zinc group' in only very low concentrations...".

Underwood, in hindsight, suggested that the initial presence of nickel in substantial quantities, and the efficacy of the bottled NiO misdirected them and they temporarily abandoned their more logical approach of group analysis. They soon found that as little as 0.1 mg of cobalt each day was immediately curative. These findings were published in June 1935. It is clear that publication was a much more rapid process then that it is usual now, as some of Underwood and Filmer's results obtained in May 1935 appeared in the June 1935 volume of the A.V.J. Meanwhile the CSIR group in Adelaide, working on the very similar 'coast disease' had published their findings reached "...through a less direct course of experimentation...", showing that cobalt in minute doses was effective in curing coast disease a few months earlier in the Journal of the Council forScientific and Industrial Research. Both groups acknowledged the work of the other in their publications.

The finding that raw liver, or dried liver, from healthy animals, and indeed meatmeal, but not liver ash, was an effective treatment led to the 1937 hypothesis that "... the potency of liver may be due to the presence of a stored factor and that cobalt may function through the production of this factor within the body". It could be that Marston's failure to obtain benefits in "coasty" animals by "... injection of relatively massive doses of active liver extract (Campolon), either alone or in conjunction with iron therapy..." negated these observations. It was eleven years before Vitamin B-12 was shown to be the cobalt-containing factor affecting haemotopoiesis and a further four years before that substance was shown to be synthesized by the rumen microorganisms. It is clear that Underwood and Filmer, and indeed Marston, were thinking of blood-forming factors because of their use of "Porculin", a preparation of dried pig's stomach containing "intrinsic" anti-pernicious anaemia factor. This was ineffective on its own, but 10 g showed a clear response with a small (0.2 g) iron ammonium citrate dose. The justifiable hypothesis of an organic cobalt compound was not followed up by Underwood, neither here nor in Wisconsin where he went on a Barksness Fellowship to work in the Biochemistry Department with E.B. Hart and C.A. Elvehjem even though his work there was really quite closely related. But at that time analytical methods were barely adequate to meet the challenge of measuring the minute quantities involved. There are many laboratories today with expensive and sensitive equipment capable of doing Underwood's chemical work in a few minutes, not years. Poor facilities, poor laboratories, and lack of money, equipment and help, together with the tyranny of travel in those days meant that every move had to be carefully thought out to make progress. Then, as now, the researcher's head was the most expensive and powerful tool.

While this work was in progress, sheep in the south west agricultural region of the state were increasing and becoming an important industry in their own right rather than self-propelled weed removers from fallow and the users of stubble. Pastures were poor, clover was rare, so that fodder in summer was, as Underwood described in his first publication, inadequate in protein and in phosphorus. To exacerbate this, rabbit populations increased to plague
proportions to the extent that black and ginger colours were frequently observed. Rabbit control by poisoning littered the countryside with carcasses, I recall picking up over a thousand carcasses in a morning and burning them. But not everyone followed this procedure and the presence of these carcasses led to widespread botulism. Poor pastures led to picas which resulted in carcass eating and ingestion of Clostridium botulinum causing deaths. The causal organism was isolated by Dr H.W. Bennetts, a toxoid vaccine produced by Dr L.B. Bull was tested by Underwood and Filmer and shown to be entirely satisfactory and was used extensively. Underwood and Shier, and later A.B. Beck, undertook the difficult task of determining the incidence, dietary basis and control of pica of the sheep in areas where botulism was prevalent. In a series of thoughtful experiments it was shown that the pica was associated with the low nutritive value of summer pastures which were unable to supply adequate quantities of protein and energy. Phosphorus supplements or supplementary feeding with cereal hays and silages or with molasses were ineffective in preventing pica as will small portions of protein concentrate without adequate energy. Unlike asphorosis in which osteophagia is characteristic, the pica of this environment was a true sarcophagia; the sheep ate flesh, not bones.

Very early in these investigations, Underwood and Shier recommended that very much more attention should be paid to pasture improvement as it was the most neglected phase of farming in the toxic paralysis areas. Topdressing with super-phosphate and the introduction of "better and more productive species such as Dwalganup" subterranean clover and others will greatly improve the nutritive conditions. Failing this, supplements of wheat, oats, lupins or peas would minimise losses.

The poor pastures of the south west and wheat belt of Western Australia result in low productivity, poor lambing, pregnancy toxoaemia and other symptoms of malnutrition. These problems were investigated in the late 1930s and early 1940s by Underwood and his colleagues in the Dept of Agriculture. On his return from the United States, Underwood was stationed at the Institute of Agriculture at the invitation of Professor J.E. Nicholls and later Professor G.A. Currie, supported by Sir David Rivett of CSIR. This gave access to laboratories and limited equipment, lamentably lacking at that time in the State Department, which was then rather poorly housed. A great number of publications emerged from this period: Studies on sheep husbandry in Western Australia I to V; biochemical aspects of nutrition relating to the botulism afflicted areas; studies on pregnancy toxoaemia, a widespread and disastrous condition in autumn lambing ewes; vitamin A in nutrition of sheep; the nutritive value of meatmeals; studies on cereal hays and pastures; and he maintained a continuing interest in trace element studies on cobalt, copper, and manganese.

Continued pressure from departmental officers for improved soil fertility and better pastures, the enthusiasm of farmers for clover containing "ley" farming systems and the greater use of superphosphate resulted in widespread dominance, and often almost pure stands, of subclover in early years. Following field and laboratory studies in 1941, H.W. Bennetts reported a specific breeding problem of great severity in sheep associated largely with the "Dwalganup" strain then widely used. This clover infertility was so severe that resources from the Department of Agriculture, the CSIR and the University were pooled and activity coordinated by an Investigation Committee chaired by Underwood and included Dr Bull and Mr Vasey of CSIRO and Dr Bennetts and Mr Shier of the State Department. The possibility of an oestrogen was early hypothesized and it was soon shown that continuous dosing with stilboestrol resulted in similar events. I assisted in dissections at an early experiment, and the clearcut evidence from that day helped set the course for subsequent work. Even the broken spring in Eric's 1937 V8 tourer on the way home, the
delay in getting it fixed, and getting pulled up by a speed cop really did not dampen the excitement of that day. Of course many years of investigations, on the chemistry and biology of the phytooestrogens, their potency, metabolic products and effects, on the management and manipulation of pastures and the breeding and selection of new clovers of low oestrogenic activity followed; some work continues to this day on the disease itself and on better clovers.

Several events in the mid 40s changed the pattern of Underwood's activities; he was appointed as Hackett Professor of Agriculture in 1946, Dean of the Faculty of Agriculture and Director of the Institute of Agriculture; he was never a director of research, but an administrator who facilitated and joined in research. The research (and teaching) resources of the Institute from University sources alone were inadequate and could not expand at a rate commensurate with an actively growing research and teaching institute. He actively sought and cultivated research fund sources and was successful in gaining support from CSIR, the Wool Research Trust funds and local industry resources. He became the main architect of the Wheat Industry funds and its forerunner, the voluntary Soil Fertility Fund. A good level of support ensured continuing research and stimulus and his "New Deal for Agriculture" document resulted in enhanced staffing which ensured the further development of research and post graduate growth; the Faculty of Agriculture has produced one-sixth of the total PhD output from the University of W.A.

Committee work and administration took considerable time and effort and steered Underwood into another activity for which he became noted world wide. An excellent lecturer his first-class and logical presentation gave rapid understanding of even the most complex material, In 1939-40 he had written a review on the "Significance of the Trace Elements in Nutrition", which attracted readers from many disciplines and firmly established him as a leader in the field. A frank readable style with clear understanding flowed readily from his pen and from a deep and inexhaustable knowledge of his subject. It encouraged him to consider expanding this article into a book "Trace Elements in Human and Animal Nutrition" which first appeared in 1958 and was revised in 1962, 1971 and 1977. A further book, "The Mineral Nutrition of Livestock" appeared in 1966. He revised it in 1980 and it was republished after his death in 1981. The numerous chapters, papers and lectures on a wide variety of subjects in his latter years maintained his caring attitude to his science and to his fellows and their environment, physical and social.

Eric Underwood was honoured by many organisations during his lifetime for his intelligent scientific work: FRS, FAA, FTS, FAIAS, FASAP, FACVS, and many honorary degrees and Society memberships came to him. But when one examines his life's researches, he clearly used the scientific method in exploring problems of agriculture and had the wit to apply the principles he found to the good of man and his animals, as had many of his great predecessors and colleagues.