Your Living Environment

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PHOSPHATE DEFICIENCY— A CRISIS WE MUST RESOLVE!

Within the past few months the world has looked askance at its sudden energy crisis, triggered prematurely by the united action of the Arab oil sheiks.

But now we have a new crisis that has gone largely unnoticed, and yet it is one that could cripple European and world agriculture almost as effectively as the oil crisis itself. You might wonder whether that is even possible. Well, it is, and the first stiff breezes of this ill-wind have already begun to blow!

During the recent oil crisis, Europe's major suppliers of North African rock-phosphate quietly and, almost without Western press comment, calmly trebled the price of their raw product!

Morocco and Tunisia, like their oil-sheik colleagues, have suddenly realized that their non-renewable source of income will one day be exhausted. Therefore they intend to cash in on the profits while supplies last. This is not to imply, however, that deposits are almost worked out now. They aren't *yet*, but the future is strictly limited.

The 'P' of 'NPK'

In nutritional terms, the greatest limiting factors to increasing world food production are firstly nitrogen, and secondly phosphorus. These are *the* two most important macro-nutrients required for plant growth (along with potassium). They form the 'N' and 'P' of the 'NPK' trio, familiar to most farmers.

And yet agriculture is suddenly threatened by diminishing reserves of both these essential elements. Industrially synthesized *nitrogen* is in relatively short supply as a direct result of the energy crisis, and *phosphate* has become recognized as another finite, non-renewable resource which MUST now be conserved. Consequently, prices of these raw materials have escalated!

In such a predicament, many farmers feel they have no alternative but to pay 'through the nose' for fertilizers their crops and soil so badly need. And yet there must be an alternative — God surely did not create an environment for man dependent upon excavation and the international transportation of underground mineral deposits.

During the past year, this Department has been researching in depth, the problem of phosphate availability — or rather, the lack of it in most soils around the world — to try to discover:

1. Why soil becomes phosphate deficient, and
2. A solution to the problem.

Our research has borne fruit — fruit which we would like to share with you in this issue of YOUR LIVING ENVIRONMENT. Depth of subject demands slightly more technical language than we normally present, but we hope its vital importance will help you stay with it.

A Problem of Availability

We have already mentioned the importance of phosphorus in agriculture, and that phosphorus deficiency presents mankind with one of the biggest obstacles to increasing world food production.

In fact, vast areas of intensively-managed agricultural land are now known to be severely deficient in availability of this element. Sir Arnold Theiler whose work on phosphate during the 1920s is now classic, found that throughout Southern Africa the country as a whole was deficient in available phosphate. Since Theiler's time, his findings have been verified by basic research. Equally low levels of available soil phosphate now exist in major agricultural regions on all five continents.

Paradoxically, few agricultural soils are deficient in actual, or total phosphorus present. Most of them contain sufficient reserves of phosphorus to support plant growth if such reserves were made available in forms which plants can assimilate. It would therefore appear that the problem is not one of *presence* but *availability* — at any one time most of the phosphorus present consists of non water-soluble forms and so it is not readily accessible to plant roots.

One writer mentions:

"With regard to phosphoric acid, the mineral apatite, the ultimate source of phosphorus in nature, is almost equally abundant in all varieties of igneous rocks, and phosphates are rarely deficient in soils derived from them . . ."
(*"Agricultural Geology"*, by R. H. Rastall, p. 35, Cambridge Univ. Press, 1922).

He continues:

"Soils derived from igneous rocks on the whole tend to be rich in potash and phosphoric acid, although these substances may not always be present in an available form in large quantity" (*Ibid*).

Since sedimentary formations have their origin in the igneous rocks, the obvious question then arises — why is this element not readily available in most soils?

Pizer explains:

"It is commonly accepted that plant roots remove monovalent H_2PO_4 - ions from soils and make little use of $HPO_4$2- and $PO_4$3-. The main sources of H_2PO_4- are attached to Ca [calcium], Al [aluminium] and Fe [iron] on *clay minerals* and *organic matter*, (this is why all fertile soils contain both clay particles and organic matter) . . . the release of H_2PO_4- depends on equilibria between a number of phases which are influenced by moisture content, pH [soil acidity] soluble salts, changes in soil structure and biological activity" (*Soil Phosphorus*, Technical Bulletin No. 13, M.A.F.F., 1965, p. 147, by N. H. Pizer). (Emphasis ours throughout.)

Organic Matter and Soil Phosphorus

Amazing as it may seem, the answer to this seemingly complex problem is perhaps far more simple than we might at first think. *Joffe* gives an indication of the simplicity of the solution in describing the phosphorus and sulphur limitations in Chernozem soils:

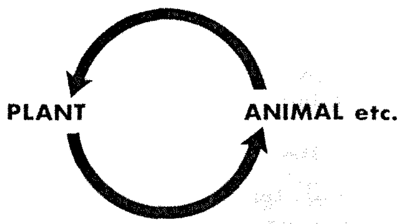
"The relatively high Ca [calcium] and N [nitrogen] contents of the A horizon [upper soil layer] are responsible for the high P [phosphorus] content in this layer. It is *the proteins of the organic matter* that furnish the key. As the organic-phosphorus compounds are mineralized, the P released ties up primarily with the Ca.

"The accumulated organic matter in the A horizon [upper soil layer] retains appreciable quantities of S [sulphur]. Its *rapid circulation* through drying plants and precipitation keeps up the supply in the surface layer in spite of the ease of leaching of sulphates. Of course, large quantities of S [sulphur] in the A horizon persist in the form of organic complexes" (*Pedology*, by Jacob S. Joffe, p. 292, 2nd Ed., 1949, Pedology Publications).

Notice that it is the *organic matter* that is the effective source of phosphorus. *Barrett* also mentions that phosphorus levels are higher in the surface soil layers than in the subsoil, and that there is often a close relationship between phosphorus levels and the amount of organic matter present (*Harnessing the Earthworm*, by Thomas J. Barrett, p. 49, 1947, Bruce Humphries Inc.).

It is well known that dead plants and animals can return appreciable quantities of phosphorus to the soil — phosphorus which has been slowly but steadily accumulating over a period of time. But such phosphorus is basically returned in organic form and is therefore not readily available for further plant growth.

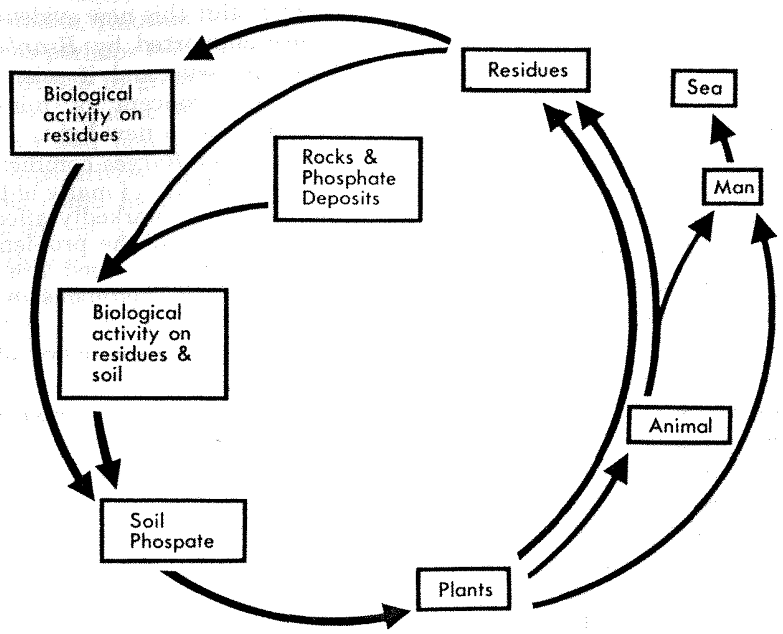
It must first be broken down by *animal* forms before it can be re-used for plant growth — thus completing one of the great ecological cycles:



The Phosphorus Cycle

These animal forms are many and varied, but two of the most important and obvious are livestock — which recycle *living* plant nutrients and earthworms — which recirculate nutrients from *dead* organic material. The more rapid the circulation of nutrients, the more stable the system — the less is the likelihood of depleting fertility and the greater are the opportunities for building up nutrient reserves. This rapid recycling of nutrients is one of the chief benefits of a live-stock-based agriculture.

The Phosphorus Cycle



Earthworms and Phosphorus

Barrett also brings out some remarkable information regarding the role of earthworms in making phosphorus available for plant growth.

He found that the phosphorus content of soil in boxes containing worms increased 10% over those which had no worms. He also analysed earthworm castings to discover that they contained *five* times as much available nitrogen, *seven* times as much phosphorus, *eleven* times as much potassium and *three* times as much magnesium as the parent soil.

Indirectly, the origin of these extra available nutrients is probably soil organic matter, on which the earthworms feed, because *Barrett* also noticed that castings contain larger bacterial populations than unworked soil. And we are well aware that soil microbes multiply on organic matter. The earthworm is therefore undoubtedly one of the major organisms directly responsible for making soil nutrients available and forms one of the vital links in the balance of nature.

In the Nile valley, fertility is legendary and it is reported that earthworm castings may amount to some 200 tons per acre per year. In most other areas the earthworm population is much smaller and the weight of castings deposited each year seldom exceeds 10 to 20 tons per acre. On many farms these castings would amount to less than one or two tons per acre per year!

Since worms appear to depend heavily on organic matter, we cannot expect to boost our earthworm population and solve major mineral deficiency problems organically, without massive returns of plant residues. There is an old truism which states that "a chain is as strong as its weakest link". And in the agricultural chain of life, the weakest link has been the return of organic residues back to the soil.

Phosphorus and Sulphur Relationships

Research on this issue of phosphate deficiency took us into many areas of mineral nutrition, one of which was sulphur. It might be worthwhile to mention here several facts we found out from other researchers about this element, since both sulphur and phosphorus have considerable bearing on the growth of legumes:

1. There is evidence that phosphate deficiencies may be accompanied by sulphur complications, and recent work in New Zealand has indicated that *sulphur* may be equally important with *phosphorus* in the growth and development of pasture legumes. *Ludecke* found that the amount of sulphur required by legumes is between one-tenth and one-fifteenth the amount of nitrogen fixed. Thus, if we consider a figure of 250 lbs. of nitrogen fixed per acre per year, somewhere between 17 and 25 lbs. of sulphur will be required of that soil.

2. But although this amount of sulphur may be sufficient to produce maximum plant growth,

Anderson (1952) reports that more sulphur is required to maintain maximum protein content. Apparently maximum growth can be achieved without a comparable achievement in protein levels! (i.e. yields are not necessarily synonymous with quality values.) *Saalbach* (1961) also studied the influence of S on plant yield and protein quality in various forage crops, and found a positive correlation between S fertilization and protein quality.

3. Pot experiments by *Needham* and *Hauge* (1952) showed that a pronounced S deficiency in lucerne caused a pronounced shortage of vitamins in the plant.

All of these facts essentially concern characteristics of *quality* in plant composition. We mention them here because they bring us back once again to the all-important factor of organic matter in soil, which, as we have seen, is not only a major source of phosphorus but also of sulphur.

4. *Barrow* (1962), *Williams* and *Steinbergs* (1958) and other researchers confirm *Joffe's* previous statement that there are always appreciable quantities of S present in organic matter and that organic residues are the major source of sulphur for plants.

5. Lastly, *Freney* and *Spencer* (1960) report that in general, soils mineralize more sulphur in the presence of growing plants than in their absence. They suggest this may be due to the "rhizosphere [root zone] effect" brought about by the secretion of amino acids and sugars and the subsequent increase in micro-organism activity.

Micro-organisms and Soil Nutrients

The bacterium Thiobacillus thio-oxidans, which is widespread in acid soils, is one of the most outstanding organisms associated with the transformation of sulphur. It can oxidize sulphur and sulphides to sulphates, and starting from mineral salts can produce 10% H_2SO_4 (Sulphuric acid).

Waksman and *Starkey* have shown that it can produce H_2SO_4 in the soil — an ability which may be significant in the transformation of insoluble rock phosphate to more soluble forms.

Kervran presents a spectacular theory that the whole genus of Thiobacilli play an important role in other aspects of sulphur and phosphorus nutrition. He presents evidence aiming to show that they are capable of *transmuting* oxygen to sulphur — not a straightforward chemical change, but a *nuclear* transformation. He also suggests that there is a probable link (via transmutation) between sulphur and phosphorus and a possible link between sulphur and magnesium (*Biological Transmutations,* 1972).

Very little is currently known about nutrient inter-relationships. They are certainly exceedingly complex. But this new evidence for transmutation — also supported by *Branfield,* further complicates the issue and if scientifically sound, puts the whole concept of mineral formation and availability in a new light.

No wonder *Burges* comments:

> "Availability of many of the plant nutrients in the soil is markedly affected by the micro-organisms, but the problems associated with the changes involved are exceedingly complex" (*Micro-organisms in the Soil,* by Alan Burges, 1958, p. 147).

Following the discovery of the importance of the Thiobacilli in sulphur availability and the probable relationship between sulphur and phosphorus, we then looked into whether one particular group of micro-organisms was principally responsible for making phosphate available.

From the limited amount of material available (mostly Russian), we found no such direct correlation. *Zimenko* (1966) investigated most of the major micro-organic forms of life except for algae — which have similar nutrient requirements to multicellular plants and protozoa — which mainly feed on bacteria. From his results, there might be a possible correlation in certain soils between phosphate availability and populations of actinomycetes and fungi, but it is difficult to assess.

Burges mentions that one type of fungi (*Basidiomycete*) traps phosphate in the lower layers of litter on the forest floor. And there is some indication that other fungi (*mycorrhizal*) in certain mutually beneficial (symbiotic) associations with tree roots, supply phosphate to some trees.

Predominance of Chicory?

Our initial thoughts on the solution to phosphate deficiency ran on somewhat similar lines to *Coccanouer's,* although they were complemented by the material *Branfield* and *Kervran* presented — i.e. that the answer lay in utilizing hitherto unused crops in the rotation to supply the missing minerals.

For example, *Branfield* shows that plants can produce their own magnesium when grown in culture mediums in which none is available.

Similarly, *Kervran* points out that when a lawn is lacking in calcium — daisies appear. When they die, they decompose leaving calcium behind for other species to take up, thus continuing the natural ecological cycles of regeneration and succession — about which we know so pitifully little!

Likewise, we wondered if there could be a plant, or a number of plants with exceptional ability for making phosphate available. Another link in the ecological chain that has perhaps been overlooked and which man could utilize to great advantage.

Research showed several aquatic plants such as duckweed (*Lemna tres.*) and pondweed (*Elodia canadensis*) to be comparatively high in phosphate — although this could have been due to unreasonably high levels of phosphate in the surface waters where they were growing.

Upon considering the various species in our own pastures, we were reminded of the outstanding success achieved in the seeding of chicory. This plant is well known for its value as a source of phosphate in animal nutrition, but its performance was especially interesting to us. Over many years, our Hertfordshire soils have traditionally and consistently tested deficient in available phosphate. Even repeated dressings of natural rock phosphate materials have effected only temporary improvements in availability of this agriculturally important mineral.

In spite of what one might describe as a chronic lack of available phosphate, the chicory plant positively flourished in our deficient environment. The other important observation in this connection is the fact that our sheep and cattle have readily devoured this species, showing an outstanding preference for it.

These observations would seem to support the idea that chicory is effective in bringing phosphate to the surface, even in soils that appear to be deficient in the mineral. At the same time, the grazing animals' sharp preferences lend weight to the belief that unhindered, they have the instinctive ability to select for themselves a minerally balanced diet. Measuring their natural preferences against the poor phosphate performance of our soils, seems to indicate that they are seeking their phosphate needs through this plant species.

As our results appear to confirm other's findings, we are more than ever inclined to the view that more research would reveal a capacity in other plants to help balance mineral availability in soils that need it.

Optimum Levels of Soil Organic Matter

We have already mentioned that organic matter contains considerable reserves of sulphur and phosphorus. Whilst the micro-organisms seem more ready to make sulphur available for plant growth, it is the earthworm population that does the main job as far as phosphate availability is concerned.

The incredible fertility achieved in the Nile valley was only possible through the vast quantities of fertile silt — containing approx. 55% organic matter in finely divided form, deposited annually by the river. This was washed down from the Ethiopian highlands and provided virtually limitless food for the teeming worm life.

If we are ever to achieve any comparable fertility, we will obviously have to make huge 'investments' in our bank of soil reserves. Until we have attained optimum levels of soil organic matter we can only expect to reap mediocre crops and breed a pitifully diminutive population of earthworms. Once we have achieved such optimum levels we will be obliged to *maintain* them with *regular* returns of organic matter — just as the Nile does each year.

Here, it would appear is the ultimate pay-off for every man and every generation willing to adopt the *GIVE* philosophy, in place of our natural human desire to *GET* and *GET* while we can — regardless of the consequences!

Are we beginning to see here one of the reasons why God has allocated *ONE THOUSAND YEARS* in His plan for man to rebuild this earth to Garden of Eden specifications?

What we are prone to forget is that most agricultural soils have been severely depleted of their natural fertility by decades or centuries of wrong methods. They have been cropped intensively with little respite and very little in the way of organic returns. We have overloaded delicate systems with demands that have been far too great, and we are now paying the penalties — penalties which cannot be eradicated overnight.

Gordon Rattray Taylor in his famous *Doomsday Book* cited the sulphur and phosphorus cycles specifically in this regard. Notice his warning.

> "Any feedback mechanism can be swamped by too big an input. The thermostat which regulates room temperature cannot maintain the temperature if you open all the windows on any icy day, or keep you cool if the house catches on fire.
>
> "And what may be more important, these mechanisms respond very slowly: so even if they can absorb the effects of human activity, they may take centuries to do so, and in the meantime conditions may be adverse for life. Man has begun to intrude on this beautifully-balanced mechanism [in context — the nitrogen cycle], as well as on the cycles which regulate the turnover of carbon, *sulphur, phosphorus,* carbon dioxide and other substances. No one knows how much overload they can tolerate" (p. 89).

Apparently the overload in the case of phosphorus has already been exceeded! Our land has been cropped far too intensively and the phosphorus taken off merely ends up in the sea.[1]

Results of Soil Tests

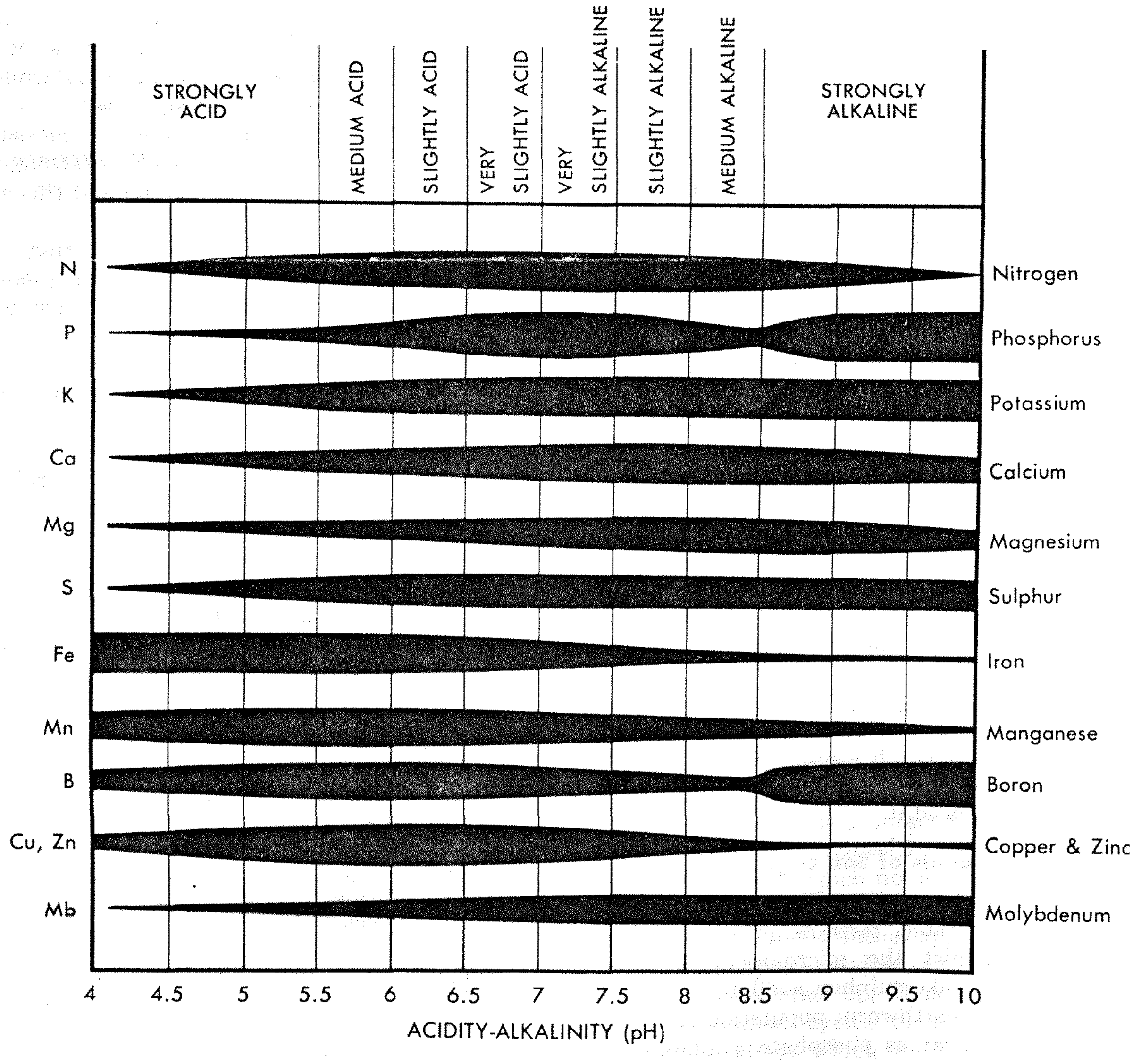
On our own farm soils in Bricket Wood, we found available phosphorus to be higher than original levels of seven years ago. Over a six month period (January to June 1973), 153 random soil tests were taken in 10 different fields. Of these, only 8 showed low availabilities, 123 gave moderate readings of varying intensities, and the remaining 22 showed phosphate availability to be at a high level. One can only deduce that organic matter and available nutrient levels are slowly improving, but that we still have a long way to go!

We need to mention one word of caution regarding soil analyses such as the ones we conducted. Soil tests (especially of P and K) can be unreliable, misleading and highly variable. Others agree:

> "There is still no foolproof method whereby the exact quantity of available phosphorus can be determined" (*South African Farmer's Weekly,* Sept. 13th, 1972).

1. Each year in the U.K. we flush 172,000 tons of phosphorus and 123,000 tons of potassium out into our rivers and coasts and hope to make up for this loss with imports of North African rock phosphate and potash from the Dead Sea totalling 700,000 tons!!

Availability of Phosphorus and Other Soil Nutrients at various levels of pH



(From "*Chemical Fertilizers*" by C. J. Pratt, (1965) in Scientific American).

But the large numbers of "moderate" availabilities obtained in our 1973 tests seem to give a fairly reliable indication of the condition of phosphorus in our soils.

Phosphorus and Soil pH

The preceding chart indicates the general trend of phosphate availability according to pH, compared with other soil nutrients. The more soluble a nutrient is under a particular condition of soil acidity or alkalinity, the thicker is the horizontal band representing the nutrient. Solubility in turn is directly related to the availability of the nutrient in an ionic form that is assimilable by the plant.

Notice that nearly all the nutrients shown are available in greatest quantities around a pH of 7 — neutral, on this scale. It is also well-known that organic matter is invaluable in stabilizing pH. When humus is present in sufficient quantity and in every stage of decay, soil pH is almost invariably neutral or near neutral.[2]

The Haughley Organic Experiment

Lawrence D. Hills, writing in the November 1972 issue of *The Ecologist* mentions that:

> "*The Soil Association,* after running a 'closed circuit' farm at Haughley for thirty years, returning all the manure and organic matter to the soil, found that the milk, eggs, meat and grain going off the farm produced a steady fall in yields" (p. 24).

He interprets this to mean that if nutrients leave the system — regardless of how high humus levels in the soil may be, nutrient availability and consequent productivity must fall. For the "closed" system, the inference is of course that nutrient availability will inevitably diminish in the absence of replenishments from outside.

On the surface, it sounds like an open and shut case! Nutrients DO escape, even from an organic cycle, but we must remember that soil is mostly *INORGANIC* and therefore as long as we have soil, we have untapped mineral reserves. The alternative is that God made a mistake at Creation and forgot the phosphate and other nutrient needs of mankind around the earth. This *mistake* would force man to transport mineral deposits around the world for the purpose of food production and/or to recycle all animal and *human* wastes.

The *first* presupposes that our environment must depend on considerable industrial development and highly expensive international transportation. The *second,* while theoretically possible, does not appear to tally with the hygiene standards of the Old Testament.

If either of these be the case — our nutritional protection would appear to be the subject of some considerable doubt, but that premise has to be rejected because, it just does not match God's performance in any other area!

What appears to be certain however, is that under the adopted TEN-year rotation,[3] although Haughley soil humus *increased* by 27% in ten years — crops took nutrients away faster than the system could replace them from internal sources! Nitrogen and potassium levels fell during this period. Phosphate levels — in crop analysis, fell slightly and soil pH became more acidic.

But we suggest that anyone would be making a grave error to postulate from these results that a *closed* system will not support mankind for the duration of at least seven thousand years. We feel that the Bible gives no support to the idea that the closed environmental system is inefficient.

Because soil with only 3% humus is acknowledged to be below the critical level[4] a decline in plant nutrients, following a 27% increase in humus, proves only that the closed system is doomed to lose efficiency *when humus is below the critical level.* It in no way disproves the ability of much higher levels of humus to release inorganic minerals commensurate with increased plant production.

One might say it would be like claiming that a gravitational pull of 20 lbs cannot be overcome — simply because we witness the results of a weightlifter exerting an opposing force of only 19 lbs! Likewise, one could raise the pH of a soil from 5.5 to 6.0 and still witness a decline in its clover population. But any agriculturalist would expect the same clover plants to proliferate with a further pH increase to 7.0, or even 6.5!

To believe otherwise concerning the function of rising levels of soil humus, is tantamount to turning thumbs down on man's future, the moment we exhaust North African and other bulk supplies of rock phosphate.

On the contrary — we feel that the Haughley Experiment confirms the need for a rotation far more heavily weighted in favour of an animal-based agriculture. And if the system is to remain

2. One notable exception is the floor of a conifer forest. The special nature of its organic content actually contributes to its acid condition.

3. The rotation consisted of: 1. winter wheat, 2. root and forage, 3. barley, 4. winter beans and spring peas, 5. oats, 6. silage of oats and peas, and 7-10. four years of pasture.

4. 3% humus was quoted as a disastrously low figure in British Midland soils by the 1969 committee of enquiry headed by Sir Emerys Jones, former Chief Advisor to the British Ministry of Agriculture.

"closed", it must be operated with judicious grazing at low intensity. Failing this, low humus levels will never allow plant productivity to really "take off". May we remind the non-agricultural reader that it CAN take off — e.g. the early years of high yields of high protein grain, on the world's black-soil plains, all with a total absence of NPK fertilizers.

Other than robbing one area of the earth to supply the demands of another, there is no alternative, if man is ever to relieve his current dependence on long-term fallow.

It may then be argued that the organic approach is uneconomic. This is probably true in the short-term, but as one ecologist said — if you accept every argument that is put forward today on the grounds of economics, you have no alternative but to conclude that it is definitely "uneconomic" for mankind to survive!

Depressing it may be, but one must therefore conclude that there is no simple way of putting prosperity in the pockets of those working the farmlands of a world that has been bleeding its soil fertility for centuries.

We just happen to be the generation living at the time of the grand pay-off. Man's survival depends on many of these men being able to hold on until a world government can change the situation.

Time Is Running Out

Temporarily, this world can go on drawing on underground phosphate reserves from Morocco, Tunisia, Florida and Nauru etc., for the immediate future — if farmers can afford the escalating prices. But this does not alter the fact that world agriculture is headed down a blind alley, a dead-end street and one day man will be forced to do an 180° turn. We will eventually have to manage our environment so that each acre of food-producing land will not only release its own phosphate for plant production, but also a whole range of other nutrients so necessary to health in plants, animals and people.

If, as it certainly appears, soil humus levels are the only long-term solution, then the sooner we get started, the less pain we will inflict upon ourselves and the sooner we will reap some of the possible rewards.

From the material studied — all the evidence indicates that in order to effect a lasting solution to the phosphate problem, farmers will in future have to:

1. Raise the levels of organic matter dramatically and stabilize the pH of the soil,
2. Maintain very high levels of organic matter to encourage a stable and large earthworm population, and
3. Recycle as much nutrient outflow as possible, or reduce economic demands on our soils.

No experiment comparable to the Haughley trials has to our knowledge been carried out on high-humus (chernozem) type soil, so it is difficult to say what level of fertility is necessary before a management system based on steps ONE and TWO, could largely dispense with the necessity of step THREE. Of course, it is extremely doubtful if it would ever make sense NOT to bother recycling most annual plant nutrient production. If it were otherwise — would we not be negating God's law of the more you GIVE, the more you GET?

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