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Erroneous ideas frequently encountered in agricultural chemistry

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Most of the misconceptions listed here were collected over the course of fifty years, mainly from practising farmers and students of agriculture. Naturally I am not suggesting that the readers of this journal are not clear about the incorrectness of most of these ideas, but some of these errors are the subject of serious debate even among specialists.

It is interesting to note that people working in other fields, who have never studied agricultural chemistry, are often more open to new knowledge than those who have. This can be attributed to both deficiencies in the teaching of agricultural chemistry and in the textbooks used, and to the fact that the basic concepts of agricultural chemistry have not been sufficiently clarified.

The vast majority of these deficiencies stem from the fact that neither the two-directional processes constantly taking place between different nutrient forms in the soil nor the quasi stationary balances consequently arising are taken into consideration.

1. Soil analyses

1.1. The aim of tests made in soil analysis laboratories is to determine the nutrient content of the soil

This is not true.

The soil analyses performed for the purposes of making fertiliser recommendations usually involve treating the soil with an extracting agent to determine how much of the nutrient in question is extracted by the given agent. In general, however, the nutrient content of the soil is hundreds of times higher than the quantity extracted during soil analysis with any solvent.

The aim of nutrient analysis in soil analysis laboratories is to provide data which, after calibration, can be used to calculate the quantity of fertiliser required to achieve the planned yield. The result of soil analysis, however, is simply a number, which is higher if the soil provides the plants with a good supply of the given nutrient, and smaller if its nutrient-supplying ability is poorer.

It is calibration that gives meaning to these numbers. The calibration would only be perfect if field experiments were performed to determine the quantity of fertiliser required to obtain the best yield at each soil analysis value.

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This is extremely costly, time-consuming work, so in most cases the experts content themselves with determining what the soil index is if the plants are well supplied by the soil with the given nutrient.

As numerous soil analysis methods exist for one and the same nutrient, this index may differ greatly depending on the method. If, for instance, the AL phosphorus analysis method is used (EGNER et al., 1960), the soil is shaken with a mixture of ammonium lactate and lactic acid (AL buffer) to measure how much phosphorus is extracted from the soil. Experiments show that soils from which AL buffer extracts a phosphorus quantity equivalent to approx. 200 mg P_2O_5 from 1000 g soil generally provide the plants with a good supply of phosphorus. Many other methods, however, use acids as extractants, in which case the value obtained for the same soil may be not 200 but roughly 1000 mg/1000 g soil, while an aqueous extract may contain only around 20 mg/1000 g.

In other words, these methods do not determine the nutrient content of the soil, as the nutrient content cannot be dependent on the method, but is a fixed quantity.

It is impossible to find a method that will extract from the soil the amount of a nutrient which is equivalent to the nutrient requirement of the plant. Plants in general do not exist. Each plant species and each desired yield level has a different nutrient requirement.

A good soil analysis method is one that only extracts as much of a nutrient from the soil as can be assumed to be proportional to the amount of this nutrient that is present in the soil in plant-available form.

Results obtained in this way depend less on the soil type; in other words, if this sort of method indicates that, at a given index value, the soil provides the plant with a good supply of the given nutrient, other soil types will also have good nutrient-supplying ability at the same or a similar value.

This is because the non-available nutrient forms are different compounds in each type of soil, while the available nutrient forms are the same for all soil types.

Soil analysis methods which extract a far larger quantity of a given nutrient than is present in available form detect the total content of this nutrient rather than the available content, which means that the value indicative of good nutrient-supplying ability is different for every soil type.

1.2. The amount of a nutrient that the plants can extract from the soil is the same as the available nutrient content of the soil

This is not true.

The available nutrient content of the soil is the nutrient quantity present in plant-available form, e.g. in the case of nitrogen: ammonium or nitrate, for phosphorus: hydrogen phosphate, for potassium: potassium ion.

The quantity of these forms in the soil can be determined, but the plant is able to take up not only the available nutrient content of the soil, but also the amount which becomes available during its life cycle. It is important to note that the available form of each nutrient is constantly being converted into non-available forms, and the non-available forms into available ones. In the stationary state the rates of the two opposing processes are the same, so an apparent (quasistationary) equilibrium is reached. The plant, however, disturbs this equilibrium when it takes up the available forms, thus stimulating available forms to be created from non-available forms, at some rate or another, in order to restore the equilibrium.

From a scientific point of view no completely insoluble compounds exist, so when the soil is shaken with the extractant used in the given method, the extract will contain not only the available forms, but also all the other forms of the nutrient present in the soil (in a quantity dependent on their solubility in the given solvent). This is confirmed by the fact that, at an AL-P_2O_5 value of 200 mg/1000 g soil, the phosphorus extracted with the AL method is equivalent to around 100 kg ha^{-1} P_2O_5 in the upper 30 cm soil layer alone, yet we know full well that in the state of equilibrium the available phosphorus content cannot be more than 2–3 kg per hectare.

1.3. The humus % (H%) values determined in soil laboratories are indicative of the percentage quantity of humic compounds in the soil

This again is not true.

The H% value is in fact proportional to the carbon %, i.e. it indicates the carbon content of the soil. The soil analysis referred to as humus determination is really the determination of the carbon content of the soil. The figure obtained represents not only the carbon content of humic compounds, but also the carbon content of all the plant and animal residues which pass through the 1 mm holes of the sieve during the preparation of the soil sample. As it is impossible to say exactly what organic compounds are present in the soil, their quantity is characterised as the carbon content.

The ratio of plant and animal residues passing through the sieve may be considerable, as the soil samples are ground up prior to analysis.

2. Plant nutrition, nutrient replacement

2.1. It is possible to determine how much fertiliser is required to achieve a good yield of individual plant species and cultivars

This is not so.

Anyone who asks us to say how much fertiliser should be applied when cultivating, for instance, a new maize hybrid, clearly does not realise that this is impossible. They usually ask us to tell them what NPK fertiliser dose is equivalent to the ‘nutrient requirements’ of the given genotype, because in general fertiliser is used as a synonym of nutrient. This quickly becomes obvious if we ask what the yield will be if the plant obtains no nutrients. The answer usually given is that it will be as much as can be produced on the soil without fertilisation, although the correct answer is that if the plant obtains no nutrients the yield will be zero.

The question reveals the lack of a basic knowledge of agricultural chemistry, as it is unable to distinguish between the nutrient requirement and the fertiliser requirement. If the fertiliser requirements could be given in this way, why would there be any need for knowledge of the growing site or for soil analysis? It is possible to say what the nutrient requirements are, as that is a property of the plant (it expresses how much nutrient the plant needs to adsorb to achieve a given yield quantity and quality). The amount of fertiliser that needs to be provided to achieve the planned yield, i.e. the fertiliser requirement, on the other hand, is not a property of the plant, but depends on the nutrient-supplying capacity of the soil at the growing site. If the soil is well supplied with nutrient, the fertiliser requirement may be zero, so no fertiliser needs to be applied, or even a negative amount, which means that the given nutrient should be removed from the soil rather than being added. For instance, spring barley of malting quality cannot be grown on a soil rich in nitrogen (after alfalfa or peas).

2.2. Fertilisation is necessary because there are too few nutrients in the soil

Once again, this is not true.

There are always far more nutrients in the soil than are required by the plants. The nutrient supply to the plant is determined not by the total nutrient content of the soil, but by the available nutrient content and by the rate at which non-available forms are converted into available forms. The reason for fertilisation is not to increase the nutrient content of the soil, but to make the nutrient-supplying capacity of the soil fast enough to provide sufficient nutrients even at the maximum rate of nutrient uptake by the plant, because otherwise the planned yield will not be achieved.

2.3. In response to P fertilisation there is a substantial rise in the soil phosphorus content and the available phosphorus content

This is not true.

Due to the great reactivity of the available phosphorus forms ($H_2PO_4^-$ and HPO_4^{2-}) the equilibrium between the non-available and available phosphorus forms in the soil comes about at a ratio of approx. 10,000:1 in the favour of non-available forms. This means that if 100 kg ha^{-1} phosphorus active agent is added to soil with an initial non-available phosphorus content of 10,000 kg ha^{-1} and an available phosphorus content of 1 kg ha^{-1}, the new quantities in the soil will be 10,099.99 kg ha^{-1} non-available P and 1.01 kg ha^{-1} available P, i.e. neither the non-available nor the available phosphorus content has increased notably. Nevertheless, the plants will clearly indicate that they have better phosphorus supplies, i.e. the phosphorus-supplying capacity of the soil has improved. The explanation for this is that although most of the phosphorus applied as fertiliser has been converted to the non-available form, these freshly formed non-available forms are able to become available at a far faster rate than the ‘old’ phosphorus forms previously present in the soil.

2.4. The nutrient-supplying capacity of the soil decreases when crops are grown because plant nutrient uptake results in a considerable reduction in the nutrient content of the soil

This is another erroneous view.

In reality the reduction cannot be considerable, because the nutrient content of the soil is many times more than the amount taken up by the plants. The real reason why the rate at which the soil supplies nutrients to the plants declines is that, among the vast number of non-available phosphorus forms in the soil, those which can be rapidly converted into available forms are gradually exhausted, so compounds with increasingly slow conversion rates are the only source of available nutrients.

2.5. Efforts should be made to ensure that the soil is well supplied with all the necessary nutrients, after which the plants will adsorb as much as they require

This is not so.

In the course of crop production, farmers aim to produce commodities with the desired quality. The nutrient supplies should be adjusted accordingly. For example, malting barley or vegetables with the quality required for making baby food cannot be grown with plentiful nitrogen supplies. The sugar content of sugar beet will also be the highest is the plants suffer from nitrogen deficiency in the months preceding harvest. Another aspect is that the yield of lettuce and alfalfa can be increased by plentiful supplies of molybdenum long after the plants have become extremely poisonous, making them unsuitable for human consumption.

2.6. Only fertilisers containing available forms of the nutrient will be effective

Not so.

As the available and non-available forms of nutrients are interconvertible in the soil, nutrients provided in non-available form may be just as effective as fertiliser containing available forms. If the non-available form is only converted slowly into the available form, this can be balanced out by the quantity of fertiliser. Farmyard manure, for instance, contains lower concentrations of nutrients than mineral fertiliser, and these are mostly present in non-available form, so larger quantities of farmyard manure must be applied. Sooner or later any non-available form becomes available, such as the potassium content of clay minerals or the phosphorus content of apatite in the course of weathering, though this may take a very long time. When the rate of conversion is this slow, the nutrient-supplying capacity will be similarly slow. As the rate at which nutrients are supplied to the plants depends on both the quality of the fertiliser and the quantity applied ($w_1 = k_1 [A]$, where w_1 is the nutrient supply rate, kg ha^{-1} day^{-1}, [A] is the non-available nutrient content of the soil, kg ha^{-1}, and k_1 is a constant characterising the quality of the non-available form, numerically equal to w_1 if $[A] = 1$ kg ha^{-1}), the nutrient-supplying capacity of the soil rises with the quantity of fertiliser. The rock phosphate used as the basic material for the manufacture of phosphorus fertiliser (fluorapatite), for example, is not effective when applied at the normal fertiliser rates, but if someone tried growing plants in rock phosphate, the plants would definitely not be phosphorus-deficient.

2.7. When calculating the nitrogen fertiliser requirements, the ammonium content of the soil extracts should also be taken in consideration

This is not true.

The ammonium ion content of the soil must indeed be taken into consideration, as the ammonium ion is an available nitrogen form; in fact some plants take up nitrogen mostly in the form of ammonium. The ammonium content of the extracts, however, is neither identical to nor even proportional to the ammonium content of the soil, since the quantity of ammonium in the extracts depends principally on the absorption ability of the soil rather than on its ammonium content. The extracts of soils with poor absorption ability and low ammonium content generally contain more ammonium than those prepared from soils with great absorption ability and high ammonium content. This means that all fertilisation recommendations, including the well-known N_{min} method, are inherently flawed, as they are based on the ammonium content of extracts made from various types of soils.

2.8. Water-soluble nutrient forms are always available to plants

Not so.

Numerous water-soluble nutrient forms exist that are not available to plants, or only to a slight extent. These include the humic acids present in soil organic matter, the polyphosphates applied as mineral fertiliser, the majority of amino acids, acid amides, amines, etc.

2.9. The liquid N fertiliser UAN (urea ammonium nitrate) is more dilute than solid nitrogen fertilisers

This too is not true.

The best-known liquid fertiliser, UAN, which contains equal proportions of urea and ammonium nitrate, may be more concentrated than solid ammonium nitrate or calcium ammonium nitrate fertilisers, as it is not simply a solution of the two compounds; a 1:1 mixture of urea and ammonium nitrate forms a liquid molecular compound with a nitrogen content of approximately 40%.

3. The humorous side of agricultural chemistry

3.1. Plants take up nutrients partly from the soil and partly from fertiliser

This is not so.

This erroneous statement can be found in numerous scientific textbooks. If fertilisation is correctly performed, the plant should not come into contact with the fertiliser, but only with the new soil arising after the soil has reacted with the fertiliser, leading to better nutrient-supplying ability. Any contact between the plant and the fertiliser should be avoided, because the high concentrations of nutrients present in fertilisers would damage the plants.

If this fact is ignored, the whole direction of research will be erroneous. It is difficult to say, for instance, what we mean by ‘fertiliser utilisation %’, or why we want to draw conclusions on the effect of fertiliser by collecting masses of data on soil analysis, yields and fertiliser doses from farms.

The yield will only be correlated with the nutrient-supplying capacity of the soil, as indicated by the results of soil analysis, if no fertiliser is applied after the soil analysis, and with the fertiliser dose only if soils with the same nutrient-supplying capacity are compared. In other cases there is no cause and effect relationship, because the yield is not produced either by the unfertilised soil or by the fertiliser without the soil. The crop only takes up nutrients from the soil that is achieved in response to fertilisation. If soil analysis was always performed after fertilisation, we would be justified in looking for correlations between soil analysis data and the yield. In the majority of cases, however, soil analysis is carried out before rather than after fertilisation, as the aim is to determine how much fertiliser should be applied.

For the above reasons, the results of soil analysis appear to indicate that the magnitude of the yield is not influenced either by the nutrient-supplying capacity of the soil or by the fertiliser dose, because larger fertiliser doses are applied if soil analysis values are low and smaller doses if the soil analysis values are high. This suggests that the same yield level may be obtained with any soil analysis values and any rate of fertiliser. The computer will process whatever data is fed in, but if there is no causal relationship between the data, any conclusions will be meaningless. Unfortunately, many such analyses have been performed. It has been demonstrated, for instance, that neither fertilisation nor soil nutrient supplies have any influence on the yield, which is, however, affected by the soil content of cobalt, titanium, rubidium, etc., i.e. any property that is not influenced by fertilisation.

The conclusions drawn from such investigations were, in most cases, not published. The results were in the same category as the well-known statistical finding that slimming diets make people fat, because people on slimming diets are more overweight than those who are not.

3.2. Soil analytical data expressed in terms of phosphorus pentoxide (P_2O_5) and potassium oxide (K_2O) are indicative of the phosphorus pentoxide and potassium oxide contents of the soil

Yet another false idea.

Neither phosphorus pentoxide nor potassium oxide can be present in the soil, since these compounds are so hygroscopic that they mix with water almost explosively. However, as we do not know what form (what phosphorus or potassium compounds) the phosphorus and potassium in the soil are present in, it is expedient to express the nutrient quantity each contains in terms of the same compound.

There are historical reasons why the oxides were chosen for this purpose. At one time the phosphorus and potassium contents of extracts were determined gravimetrically (based on weight). In other words, the extract was evaporated and the residue was put in a combustion chamber, where the phosphorus and potassium were converted into oxides. The weight of these oxides was then measured.

In some countries the extracted quantity is given not as oxides, but in terms of elemental phosphorus and potassium, so people reading papers in foreign journals are often surprised to see how low the PK contents of the soils are in the given country. (It should be noted that elemental phosphorus and potassium are not present in the soil either. The practice of converting them into oxides is similar to the fact that the organic matter content of the soil is given as C%, or the hardness of water in terms of CaO, although the water cannot possibly contain calcium oxide, i.e. quicklime.)

In the case of plant analysis, the element contents are not expressed in oxide form.

If we read, for instance, that the AL-P_2O_5 content of the soil is 150 mg per 1000 g, this means that the AL-soluble phosphorus content of the soil is *equivalent* to 150 mg phosphorus pentoxide per kg.

3.3. When the active ingredient content of the fertiliser is given as N%, P_2O_5% and K_2O%, this means that the 'active ingredients' in the fertiliser are N, P_2O_5 and K_2O

This is another misunderstanding.

Neither elemental nitrogen, nor phosphorus pentoxide, nor potassium oxide are present in fertilisers. The nitrogen, phosphorus and potassium contents of the fertilisers are converted into these values. The active ingredients in nitrogen fertilisers are generally ammonium nitrate (NH_4NO_3) or urea [$(NH_2)_2CO$], while phosphorus fertilisers contain calcium dihydrophosphate [$Ca(H_2PO_4)_2$] and potassium fertilisers potassium chloride (KCl) or potassium sulphate (K_2SO_4).

3.4. Plants absorb carbon from the humus content of the soil

Not so.

Plants take up carbon from the carbon dioxide (CO_2) in the air. Fungi take up carbon from the soil, but they are neither plants nor animals.

3.5. Plants take up nitrogen from the molecular nitrogen in the air

Again, this is not so.

Only nitrogen-fixing bacteria are able to take up nitrogen from the molecular nitrogen in the air.

3.6. Plants are supplied with nitrogen by the humic substances in the soil

Another misconception.

The nitrogen supplied by the soil comes primarily from partially decomposed or decomposing plant and animal residues, not from true humic substances. True humic substances are the extremely stable N compounds remaining after humification, which exhibit very little further decomposition. It can be demonstrated using the carbon isotope method that some of these compounds are several hundred years old. Their chief benefit is that they form a crumbly soil structure by binding the mineral particles in the soil.

3.7. Nutrient deficiency is caused by the lack of a certain nutrient in the soil

This is not true.

The reason for nutrient deficiency is not that there are too few nutrients in the soil, since the nutrient content of the soil is always several hundred or even several thousand times greater than the nutrient quantity required to obtain the maximum possible yield.

Nutrient deficiency develops if at some stage of the plant life cycle, the plant needs to take up the given nutrient at a greater rate than the rate at which the soil is able to supply it.

(If the desired yield level is higher than what can possibly be achieved, we cannot speak of nutrient deficiency in this sense, as the nutrient requirements of a lower yield will certainly be satisfied.)

3.8. The Mitscherlich law of diminishing returns contradicts Liebig's law, as it states that yields can only be increased up to a certain level

This is again a misconception.

According to Liebig's Law, the yield will increase linearly with the fertiliser dose (enhanced nutrient supplies) if the reason for fertiliser application is that poor nutrient supplies are the yield-limiting factor.

Mitscherlich's Law, on the other hand, describes what happens if nutrient supplies continue to be increased when nutrient supplies are no longer the yield-limiting factor. In such a case, the yield will no longer increase linearly with the higher fertiliser rate, but to an ever lower extent, and after a maximum is achieved, a decrease in the yield can be expected. Current scientific knowledge, however, indicates that if other yield-limiting factors (e.g. cultivar, water supplies, stand density, light conditions, etc.) are also improved, yields could still be increased to far above the present limits.

3.9. The effectiveness and efficiency of a fertiliser mean the same thing

Not really.

If a fertiliser is applied and the yield increases, we can say that fertilisation was *effective*. If, on the other hand, we calculate the extent to which the yield was increased by 1 kg fertiliser, or the profit obtained per unit fertiliser cost, then we are talking about *efficiency*.

3.10. The 'min' in the name of the N_{min} fertilisation recommendation system is the abbreviation of minimum

This is not so.

The N_{min} method used in many countries is a fertilisation recommendation system where the nitrogen fertiliser requirement is estimated not from the humus content, but from the mineral nitrogen content (NO_3^- + NH_4^+) in a soil extract prepared using diluted salt solution. So 'min' stands for mineral.

3.11. The AL in the name of the AL method refers to aluminium

Not at all.

It is the abbreviation for the extractant, ammonium lactate buffer.

3.12. As a 100% slope would have a 90° angle of slope, a 45° slope is equivalent to a 50% slope

This a misconception.

A 1% slope is one which rises or drops 1 m over 100 m. The rise or drop is the sine of the angle of slope. So the elevation of a 45° slope is sine 45°, which is approximately 0.7. If this is multiplied by 100, the 45° slope will be found to have a 70% slope.

3.13. The EUF instrument measures nutrient contents

Not so.

The EUF, or electro-ultrafiltration instrument (NÉMETH 1971), can be used to prepare aqueous soil extracts, the nutrient content of which must be determined with analytical methods, like any other soil extract.

It has the advantage that, depending on the size of the electric voltage applied, nutrient fractions that become available rapidly or slowly can be prepared. This technique is used in many countries by the grape vine and sugar beet advisory services.

3.14. Yield differences of 1–2% can be detected in field experiments

This is not true.

Even scientists performing long-term small-plot experiments using the best possible apparatus are unable to prove differences of less than 4–5% between treatments. So products promising yield increases of 1–3% should be treated with caution.

No conclusions should be drawn from farm-scale experiments where no replications are included.

Experiments involving nutrient supplies, fertilisation or yield-enhancing products are radically different from plant protection experiments from this point of view, as the latter provide reliable results without any special techniques. This is because plant protection experiments are usually aimed at determining whether the weed or pest is destroyed or not. If plant protection experiments were expected to determine whether the weeds or pests were reduced by 1–2%, they would encounter similar difficulties, but obviously such questions do not arise in this case.

Conclusions

To conclude, when talking to increasingly knowledgeable farmers, I have often been asked questions that could not be answered without clarifying the above points. It is generally thought that calculating fertiliser requirements is a very simple matter: chemists determine in the laboratory how much of each nutrient the plant is able to take up from the soil, and if this is less than the nutrient requirement of the plant, the difference must be applied as fertiliser.

Apart from providing basic practical knowledge, the points covered in this paper are also of scientific significance. They can prevent not only the drawing of erroneous conclusions from experimental results but also the designation of false research directions. For instance, if the theoretical background of criteria for good soil analysis methods had been clarified a lot earlier, scientists would have been saved almost a hundred years of empirical research. Fortunately, although at present there are almost a hundred known methods for phosphorus analysis alone, care is increasingly being taken to use solvents that can be expected to extract only as much nutrient from the soil as is proportional to the available forms.

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