Adoption level is the most underestimated factor in fertiliser recommendations

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Chapter 1:

What 20 years of experience has taught me about making fertiliser recommendations

A fertiliser recommendation serves to provide the land-user (who is most often a farmer) with advice on how best to manage the fertility, i.e. the productive capacity, of his or her land. Putting it like this, it seems like a remarkable simple exercise. Then why is there so much fuss about it? After nearly 20 years research in soil fertility and nutrient management I came to some conclusions...

The crux is in the application of the fertilisers, not in the fertilisers themselves

Let's first go into the fuss.... Fertiliser recommendations typically address mineral fertilisers, that is those fertilisers that originate from mines (P and K) or from air (N). And there are some terrible stories of what can happen when mineral fertilisers are used in the wrong way. In 2015 the report 'A Soiled Reputation' on the adverse impact of mineral fertilisers in (tropical) agriculture was published ([1]). It fueled the, sometimes fierce, discussion between supporters of 'organic' fertilisers and those who use 'mineral' fertilisers. However, the crux is in the application of the fertilisers, not in the fertilisers themselves. Compare it with food: there is nothing wrong with food by itself, there are only wrong food habits... Fertiliser applications are like food habits: you have to know what you are doing, otherwise the cure may become a cause. So, when properly addressed, fertilisers, preferably a combination of mineral and organic sources, can have a great and positive impacts on crop growth and food production.

Fertiliser recommendations that are environmentally sound and support plant growth, maintain soil health

Notably, about 50% of the global population depends on mineral fertilisers for their food intake ([2]). I am absolutely in favour of organic fertilisers, but simply banning mineral fertilisers would be a cruelty against mankind. So, what we need to do is to make proper fertilisers. There is a great review ([3]) about some popular myths in soil fertility, many of them relating to confusions about sources of fertilisers. The authors conclude "These myths need correction if we are to harness the role of science in the overall goal of assisting farmers to address the acute problems of poor soil fertility for smallholder farmers in sub Sahara Africa". I cannot agree more. We need fertiliser recommendations that support plant growth, maintain soil health and are environmentally sound.

What makes a proper fertiliser recommendation?

But what makes a fertiliser recommendation a proper one? Well... that depends on the objective of the recommendation. Scientists typically distinguish 3 objectives:

- maximum yield level
- maximum rate of return
- maximum crop response, for example the highest yield response per amount of fertiliser applied.

The 3 different objectives

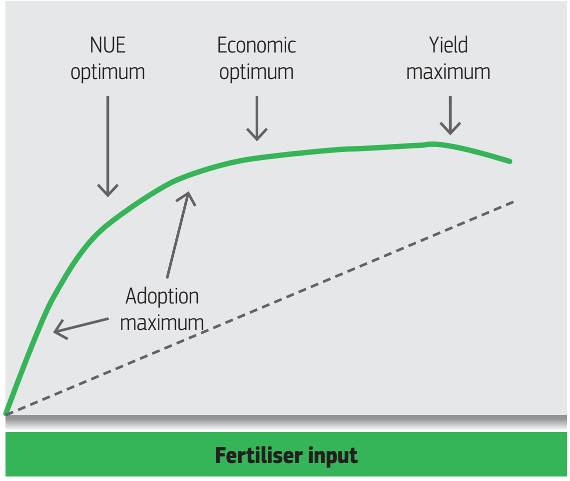

Figure 1. *Scientists often distinguish 3 types of fertiliser recommendation objectives based on either crop performance (maximum yield or maximum response) or on economic performance. In this paper the objective of maximum adoption is put forward.*

New objective for fertiliser recommendations: the adoption maximum.

However, in my view, the most important objective, at least for developing countries, is often missing, namely the highest adoption level. I therefore hereby postulate a new objective for fertiliser recommendations: the adoption maximum.

A perfect recommendation is pointless without the adoption of the farmer

Adoption is the extent to which people are willing and capable of bringing a recommendation into practice. Thus there is little relevance of developing a recommendation that is not brought into practice. And here is the shocking news: adoption rates of fertiliser recommendations are often appallingly low. They are typically less than 50% ([4]). In other words: you can make a beautiful near to perfect recommendation, but what is the point of it, when it is not adopted by farmers?

This brings me to my favourite hobby-horse: the issue of fertiliser adoption by (especially) smallholder farmers. I am increasingly intrigued by this topic, it is so fascinating!

Chapter 2:

From early adopters to a revolution in agriculture

What drives the adoption of best practices of smallholder farmers in rural Africa? According to literature ([5,6,7]) there are, of course, several factors, which I summarise as:

- **1) Personality**
- This factor relates to the famous adopters graph of Rogers (1962). This graph estimates that only about 15% of the population can be regarded as innovators and early adopters. They are the ones that will take up the innovations from start on. The other way around, the theory explains that 100% adoption will never be achieved from start on, whatever you do. There are recent modifications to this theory, which take into account the wider context of the farmer (number), but the conclusion remains the same; you cannot get 100% adoption because of different farmer realities.
- **2) Enabling environment**
- This factor contains the tools, skills and availability of the farmers to implement the recommendations. For example, if the recommended fertilisers are not available, adoption is (logically) nil.
- **3) Supporting environment**
- This factor relates to the extent to which farmers are motivated and supported to reach out. Are risks covered by insurances or by the social structure? The more supporting the environment, the higher the adoption.
- **4) Closeness of the recommendation**
- This one I added myself. I think it makes sense and it relates to the difference the recommendation makes compared to the existing practice. Just imagine you get a recommendation that is completely different from your current practice. Well I reckon you will be less willing to change your daily practice compared to a recommendation that will only slightly affect your current practices. However, being too close to the current practice will also not have much impact. Then it is just a continuation of the current situation, which some call 'recycling poverty' ([8]).

The adoption maximum starts close to common practice and increases in time

These four factors have a close interaction; one cannot go without the other. The 'trick' is to put them all in place. Making a fertiliser recommendation that contains only locally available inputs, is supported by the community and is close (but not equal) to existing practices. The highest impact is made when the recommendation is a considerable improvement compared to the current practice and is applied.In other words it is adopted by many farmers. Therefore, I consider the adoption maximum as a trajectory, instead of a static figure. It starts close to the current practice and increases in time.

Chapter 3:

So many roads to Rome

Back to the techniques of making a fertiliser recommendation. Again, there are some decisions to make, starting with the fundamental approach of the recommendation. This is followed by the input parameters used and the way they are derived.
Fertiliser recommendations basically serve to restore or maintain the productive capacity of the soil. Therefore, they commonly consider the soil status and the amount of nutrients withdrawn by crops. To do so, one can use one of the following methods:

1. Balance method
Apply as much as is withdrawn from the system taking into account managed (e.g.harvest) and un-managed (e.g. erosion) losses. This method is sound and clear, but assumes that the soil is currently in good condition. If this is not the case, this approach will 'recycle poverty'.

2. Threshold method
When the content of a certain element in soil is below a specific threshold; it is applied to the level in which it is not insufficient anymore. This method is widely used, but the correct determination of the threshold is difficult, nor does it consider interactions between nutrients.

3. Trial and error
Different combinations of fertilisers are applied and one looks at the highest yield response. Although this is not very scientific; the approach is often used ([9]).

4. Yield response method
This method is based on field experiments in which a relationship is determined between the amount of fertilisers and the yields obtained per crop. Apart from the costs of doing extensive field trials, the method is also only valid within the area of the experiment.

5. Simulation modelling,
Empirical, semi empirical and physiological relations are used to calculate the exact fertiliser requirement. This method is actually only applicable for scientists and requires substantial amounts of data.

Combination of different techniques

Often, the methods above are combined. For example, a threshold is corrected with a balance method, or the yield response curve is used for simulation modelling. Many examples of the above methods can be found in Ethiopia, which is currently reviewing its fertiliser policy ([9]). Notwithstanding the method, all except the balance method require soil data.
Soil data can be obtained from wet chemistry laboratories or from 'dry chemistry', which uses spectrometers like the technology developed at SoilCares (now part of AgroCares).

Chapter 4:

The soil mystery

Soil data is used to develop fertiliser recommendations as it reflects the stock of nutrients in the soil that the crop can extract. Conventional laboratory procedures can only measure nutrient concentrations in a solution. One of the most critical aspects in conventional soil laboratories is the choice of the most relevant extraction method. Notably, parts of the nutrients are readily available (i.e. already in solution). Other parts are sorbed to the soil complex and can become available after desorption.To some extent, crops can stimulate the desorption of nutrients from the soil complex. Hence, the 'trick' of conventional laboratories is to use an extraction method that indicates the availability of nutrients in the soil for crop uptake at several time scales. And here starts the fussiness.

What extraction represents the availability of nutrients best?

Extractants are solutions where the solutes replace sorbed nutrients to a lower or higher extent. The fussiness is about the extent of replacement. Imagine a very weak extractant (e.g.water or calcium chloride). It will desorb only a very small fraction of the adsorbed nutrients, whereas a very strong extractant will solubise a much higher fraction. Scientists have been arguing for decades about what extent of extraction best represents the availability of nutrients during a cropping season and can thus be of best use for developing fertiliser recommendations. Excuse me, but I largely consider this a trivial discussion.

We should look at a wider context of use

In my view, we should not look at the soil parameter in isolation, but in its wider context of use. In the context of fertiliser recommendation, this is to represent the seasonally available stock of nutrients, which is then used in an equation that in its very basics looks like this:

Fertiliser recommendation =
(crop uptake + unavoidable losses – soil stock) * α

where the factor α represents all kinds of fertiliser efficiencies and crop uptake efficiencies. I argue that if the soil stock is determined with a weak extractant, α will become larger and when the soil stock is determined with a strong extractant, α will become smaller. This means, amongst others, that field trials are needed to validate the fertiliser recommendation, no matter what approach is used. This, is something scientists all over the world agree on.

Alternative approaches: sensor technology

For some time, there are alternative approaches available for the determination of the soil nutrients, which I think are very promising. Others, by the way, concur that indeed sensor technology can cause a paradigm shift in agriculture (e.g. Bushong et al., 2016; Viscarra Rossel and Bouma, 2016). In short, sensors (mid infrared and/or near infrared) measure the electromagnetic spectrum of a medium, in this case soil. This spectrum is subsequently converted into the required data using prediction models based on a calibration database. Obviously, the accuracy of this methodology largely depends on the accuracy and comprehensiveness of the calibration database and the algorithms used to do the conversions.

Sensor based technologies in general provide total contents, namely the amounts of nutrients. As explained above, I argue that fertiliser recommendations can be correctly determined irrespective of the chemical parameter as long as the parameter is adjusted accordingly. I therefore proclaim that instead of comparing conventionally determined soil data (i.e. determined by a wet chemistry laboratory) with sensor based data, fertiliser recommendations for a specific yield target for a specific crop at a specific site should be compared, if one wants to judge the applicability of sensor based technologies for developing fertiliser recommendations.

Trial in Kenya

This is exactly what happened in a small trial in Kenya. In two sites soil samples were taken by a conventional ('wet chemistry') laboratory and by a sensor-based ('dry chemistry') laboratory. Both organisations were asked to provide recommendations for a target yield of 35 bags per acre (6000 kg per hectare). Independently, the two organisations reported nearly similar recommendations despite very different procedures to determine the soil status (Figure 2).

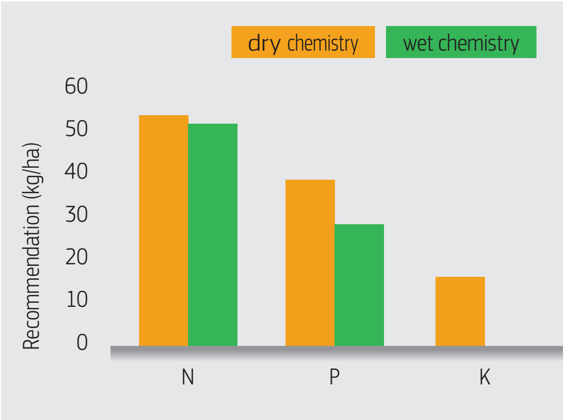

Figure 2. *Fertiliser recommendations developed for maize in Kenya based on conventional soil chemical methodologies (wet chemistry) and based on sensor technologies (dry chemistry).*

Figure 2 shows that proper fertiliser recommendations can be developed irrespective of the laboratory method used to determine the soil nutrient stock.

Crops are like humans: what you eat is what you get

In this chapter I come back to the analogy between crop nutrition and human nutrition: a healthy diet is diverse and contains different essential elements. If we feed the soil correctly, the crop can take up just that diversity of nutrients that makes a healthy crop. There is also an analogy between the available nutrient determinations of wet chemistry laboratories and the total amounts determined by sensor based methods. The Dutch Nutrition Institute recommends people to consume 75 mg Vitamin C per day *(www.voedingscentrum.nl)*. It could also recommend people to eat 1.5 oranges per day, or 125 g strawberries. The recommendations are the same (i.e. is the total intake), only the numbers are different.

A fertilizer advice is based on the soil status and the nutrient requirements of the crop. The nutrients requirements of the crop depend on the crop type and on the target yield. A high nutrient demanding crop at a high target yield needs a lot of nutrients.

Figure 3. SoilCares Foundation publishes booklets to explain the concepts of soil fertility management to smallholder farmers. In this example, the issue of target yields is explained. Again, the analogy with human performance is made. Free sample version of the booklets can be downloaded from *www.soilcaresfoundation.org*.

We have the means to improve soil fertility. PLEASE act!

In this writing I tried to share my view on soil fertility management. It is the sole primary production factors millions of smallholder farmers dwell upon and it is deteriorating at an unprecedented speed. Already, more than 12 millions of hectares of potentially productive land is taken out of production each year, because of improper land management([10]). The International Food and Policy Research Institute (IFPRI) estimated the costs caused by injudicious soil management at US$ 231 billion per year ([11]). Millions of smallholder farmers are struggling to survive each day and the productive capacity of their land is one of the main factors determining their survival. We have the means to improve soil fertility. However, the soil scientific community is not unified and debates about best approaches continue. Don't get me wrong, I am very much in favour of scientific discussions, and they should be held, often and well thought out. But in the meantime, please, PLEASE act! Even if the soil recommendations are not perfect, the impact can be considerable. There is no need for waiting, the farmers are waiting for us. Let's go and help them.

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