

How do the true costs of nitrogen fertiliser influence crop rotation?

In light of global warming and an increasing focus on sustainability, the agricultural sector has much to gain. Meanwhile, the sector faces an increase in demand due to the growing population. The challenge they are now facing is to maintain high crop yields, but in the meantime, reduce their environmental impact. One major aspect of this challenge relates to the production and application of nitrogen fertiliser. Including these fertiliser related impacts, using True Cost Accounting, in the decision-making process for which crops to grow as an arable farmer can lead to different choices for the crops planted and the rotation schedule used.

In a simplified view, a farm wishes to maximise its profit, which is calculated by subtracting the costs from the revenue. We only consider the costs of fertiliser usage, as the other costs are not affected by the management decision included in our model. Similarly, it is assumed that the revenue comes solely from the sale of the realised crop yield. The test data consists of four crops (A, B, C, L), where crop L is a legume. Their revenue (yield*price) and fertiliser requirements per hectare are shown in figure 1. The outcome of the model for different fertiliser prices is then shown in figure 2. Based on this figure, it becomes evident by, that depending on the fertiliser price, different choices are made. At a low price, the crop with the highest revenue (crop B) is chosen. However, as the price increases, it moves towards the crop with the lowest fertiliser requirements (crop L). Figure 3 shows that even though the revenue of the crop sale decreases, the reduction in costs makes crop L more profitable at that price.

Visualisation of the revenue and fertilizer requirements of each crop

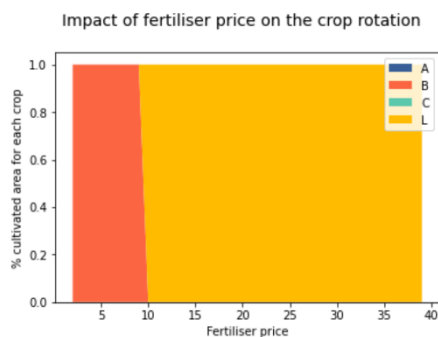
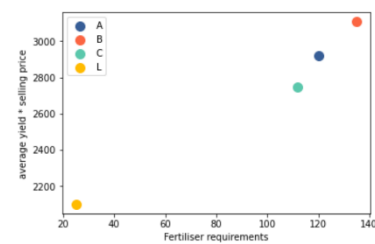


Figure 2

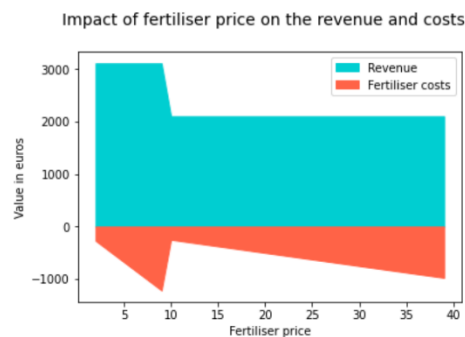


Figure 3

The idea behind the price increase relates to the True Cost Accounting. This way, not only the market price of nitrogen fertiliser is included, but also the external costs that come with the environmental impact. The production of nitrogen fertiliser is highly energy-consuming (Ahlgren et al., 2010), and its application can lead to leaching (nitrogen ends up in the groundwater) or emissions of greenhouse gases.

This base model results in a crop rotation containing only one crop, which is defined as monocropping. However, monocropping causes soil depletion and stimulates pest growth. Consequently, the more years the same crop is grown, the more the yield is affected negatively. It is therefore important to take these rotational effects into account. Another relevant effect is observed with legumes, which can fix nitrogen from the air. In other words, legumes are (partly) self-providing in their nitrogen needs. In addition, there are several studies that show that if a legume is grown, it leaves nitrogen in the soil

which can be used by the next crop (Stagnari et al, 2017). This implies that if a legume is included in the crop rotation, the amount of nitrogen fertiliser for the succeeding crop is decreased.

To take both effects into consideration, the base model is extended based on the model introduced by El-Nazer and McCarl (1986). The objective is to maximise the profit, which is calculated the same way as in the base model. However, the yield of a crop is now influenced by its crops planted in the two preceding seasons. This implies that if there is monocropping present in the sequence, then the yield of that crop is reduced by some factor m . This is shown in figure 4 for crop A. A yield potential of 1 implies that hundred percent of the yield will be realised. If crop A appears again in the rotation, then the yield decreases. Moreover, if the predecessor of that crop is a legume, then the amount of fertiliser that is needed gets reduced with n (relative amount). In this case crop L stands for the legume and if it is directly preceding the current crop, the nitrogen-fixing effect comes into play and the required amount of fertiliser drops, as can be seen in figure 5.

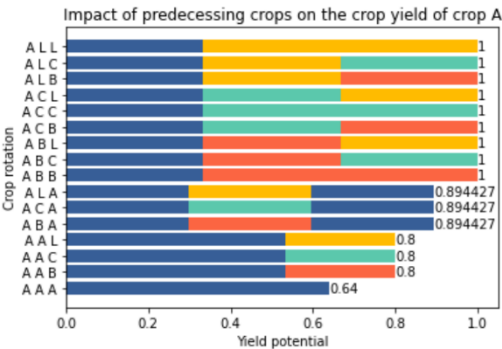


Figure 4

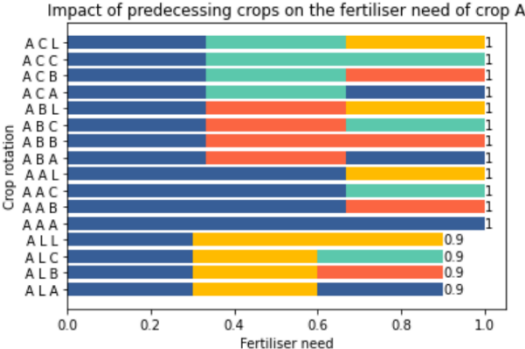


Figure 5

Figure 6 shows the area used by each crop in the optimal rotation, for different values of the monocropping effect, fertiliser reduction and fertiliser price. The crop rotation is fully diversified (in the three-season window) at low fertiliser costs, i.e., when the True Cost Accounting is not considered. However, as this price is increased to take environmental impacts into account, the rotation incorporates more legumes and eventually fully converts to legumes. These results hold for different parameter values (m, n), with differences mostly in the timing of changes.

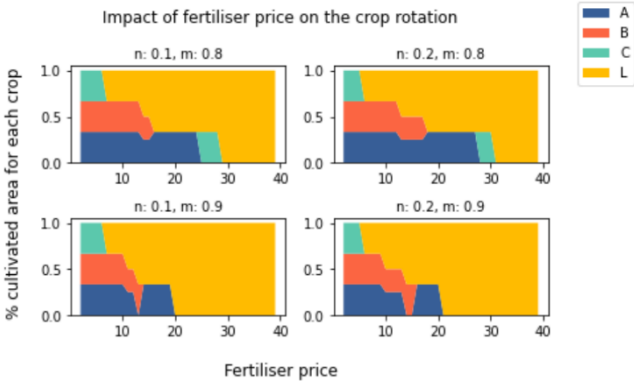


Figure 6

The cost of the fertiliser is the main driver to the changes in the rotation. As the price increases, it becomes more profitable to include legumes due to their low fertiliser requirements, and their fertiliser reducing effects on other crops in the rotation. This is why at every jump in the graphs in figure 7 there are more legumes implemented in the rotation.

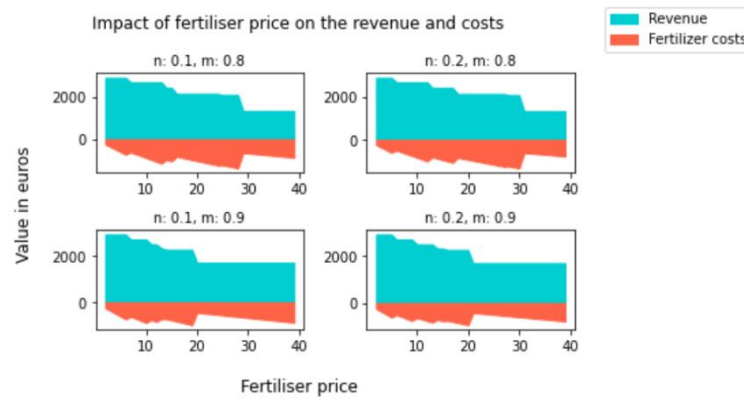


Figure 7

The model in this article focused on the monocropping effect and the special characteristics of legumes. Consequently, the rotational effects depend on only two parameters (m , n). Nevertheless, the model itself can take all sorts of rotational influences into account, such as pesticides use and management practises. Moreover, the model also supports the parameters to be crop-specific. Even though increasing the fertiliser price in practice would lead to higher prices of the crops, the main point still holds: taking advantage of rotational effects can reduce the costs and the environmental impact of a farm.

This model can be further improved in several ways. It can be the case that one of the crops that might be excluded by the model is necessary to grow. Therefore, minimum yield levels for each of the crops can be included as a constraint. Moreover, the price and yield are now considered to be fixed. Using stochastic programming, this uncertainty can be considered explicitly. Additionally, the model currently allocates one to the land per year. However, not all crops have the same sowing or harvesting period. Hence, the model's time scale can be refined to allow for multiple crops per year as well as cover crops and fallow periods.

References

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Stagnari, F., Maggio, A., Galieni, A. & Pisante, M. (2017). Multiple benefits of legumes for agriculture sustainability: an overview. *Chem. Biol. Technol. Agric.* 4, 2.