Optimization Methods to Maximize Farmer Revenues in India

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Introduction

India is a populous country , no doubt for that, we have crossed the 1 billion mark 20 years back in 2000 (Mackinnon). Currently, our population is around 1.38 billion (World Bank) which means that every seventh person on the earth is Indian. Moreover, our population growth is a bit more than 1% every year since 2009 which is concerningly high. As we grow, demand for food, clothes, and land also increase. We notice that the population growth shrinks the land available for farming but the basic requirement like food or clothes leaps. So, there is a clear reason for being productive in farming and following the farming model which could benefit both farmers and the government. One way of achieving higher production is to incorporate a multi-layer farming model in the farms of India, which I set out to study earlier this year. However, obtaining an “ideal” resource model for farming turned out to be exceptionally difficult.

Production seems to be a simple term and easy to grasp and estimate, but this is not the scenario as it has many intricacies. These intricacies can be the factors on which the production depends such as input quality of seeds, fertilizers, water, sunlight, soil type, labour used and many more. Some of the above factors are not in human control and are difficult to consistently measure, such as sunlight and rain. Still, some factors are measurable and changeable, for example, seed quality, fertilizers or labour which can help us enhance our production. More production signifies a more vital benefit to the farmer, the profits will proliferate and alleviate the suffering of the famer being in poverty, which the majority of farmers in India are in (Economic Times).

In this research paper, I will be using the mathematics of optimization to determine the factors on which farmers can oversee and increase their profit overall. As mentioned previously, production in multi-layer farming (or any other modern agriculture) depends on a number of variable factors, so it is often a multivariate optimization scenario. However, in addition to traditional partial derivative solutions, the paper will also explore single-variable solutions and a machine learning approach to understand the breadth of optimization techniques available for applications in agricultural software development, research, and even direct use by farmers.

Single-Variable Calculus Method

The preferred method of single-variable optimization involves using the fundamental laws of calculus to obtain either the maximum or minimum point of a continuous or semi-continuous function. It is easy to use and implement the problem of optimization when there is only one variable present in the equation. Dealing with the least number of variables is always beneficial as there is less complexity while solving the equation. As the number of variables increases, the complexity also increases in graphs. Single-variable optimization problems can be drawn on a 2-D graph which are easily comprehensible and can encapsulate mathematical information in practically useful ways. Two-axes graphs can help farmers or technical consultants to understand the matter and work accordingly on the farm, which may be exceptionally difficult with higher-order representations. Single-variable optimization easily allows us to oversee how to maximise profit, revenue or any other outputs while minimising the cost, electricity usage and other inputs. An example of a single-variable production function is as follows:

$$P(x) = \sin(x^{-2} + 3) + 1,\ 0.15 \leq x \leq 0.20$$

This could be solved graphically by plotting P(x) against x, observing the maximum points of the graph, as shown in Figure 1. These can also be calculated manually through the process of differentiation, by setting the derivative $P'(x) = 0$, which can be solved for the critical points of the function (i.e. where the function is either stationary or has a turning point). The second derivative test then enables us to test for the concavity of the function at any given point, depending on the value of $P''(x)$. These two standard processes can maximize virtually any solvable equation in one variable, given that a distinct maximum or minimum point actually exists.

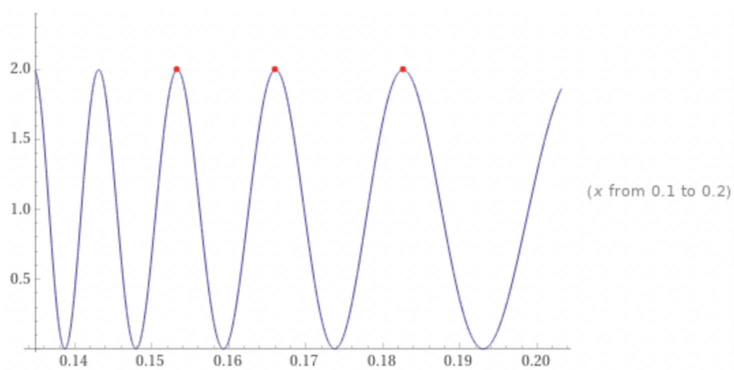

Figure 1. Maximum points for P(x)

This research deals with the multi-layer farming model, which has been described before, so there are several aspects of the single-optimization that do not work in the model and thus, have some disadvantages to use. We can not perform this optimization on a profit function that needs multiple variables to work properly. For example, profit of a farm may depend on the seed quality and quantity of water used simultaneously. We cannot isolate these variables of optimization without necessarily sacrificing some level of detail in the model. To derive a single-variable calculus solution, we also need to know the relationship of every variable or factor present in the problem and sufficiently encapsulate it in two variables. For instance, we would need to understand the dependency or connection between water used, fertilizer, and labour used , if possible, to proceed with the process of forming equations.

Multivariable Calculus Method

Multivariable optimization deals with functions of multiple variables and gives us the maximum and minimum point of the function. Multivariable equations are equations that have two or more unknowns (usually represented by$x$ and y, or x_1, x_2, x_3... x_n). We can use the characteristics of partial derivatives to maximize a function with two inputs and a single output. The sample production function we will optimize is as follows:

$$f(x, y) = 3\sin^2(y - 4) - 0.17(x - 6)^2 - 0.32y^2;\ x, y > 0$$

Finding the maximum point of a multivariable function generally involves performing a series of relevant tests to obtain its critical points, which can then be tested further to isolate each one as a maximum or minimum. Using the standard procedure for multivariable optimization, we can try a few of these tests:

1. Calculation of first partial derivatives
   a. $\frac{\partial}{\partial x} 3\sin^2(y - 4) - 0.17(x - 6)^2 - 0.32y^2 = -0.34(x - 6)$
   b. $\frac{\partial}{\partial y} 3\sin^2(y - 4) - 0.17(x - 6)^2 - 0.32y^2 = -0.64y - 6\sin(4 - y)\cos(4 - y)$
2. Setting partial derivatives to zero to find critical points
   a. $f_x = 0 \Rightarrow x = 6,\ y \in R$
   b. $f_y = 0 \Rightarrow x \in R,\ y \approx 2.18656,\ 0.961725$
3. Finding points where $f_x = f_y = 0$
   a. $P_1(x, y) = (6, 2.18656)$
   b. $P_1(x, y) = (6, 0.961725)$
4. Calculating $f(x, y)$for each pair
   a. $f(P_1) = 1.29688$
   b. $f(P_2) =- 0.264063$
5. $f(P_1) > f(P_2)$ so we will disregard P_2
6. Second Derivative Test
   a. $H = f_{xx}(x, y)f_{yy}(x, y) - (f_{xy}(x, y))^2$
   b. For P_1, $H = 0 * (-5.94725) - 0 = 0 \Rightarrow$ Inconclusive

Unfortunately, none of the partial derivative calculations can help us isolate a maximum point for this specific function. This is often the case in multivariable calculations, and such obstacles cannot be predicted beforehand. With the help of graphing technology (in this case, Wolfram

Alpha and Grapher), we can use the critical points calculated earlier to conclusively find a local maximum for $f(x, y)$in the domain $x, y > 0$. In Figure 2 below, the blue point $P_1$is clearly a maximum point, but we could not have known this based on arithmetic calculations alone.

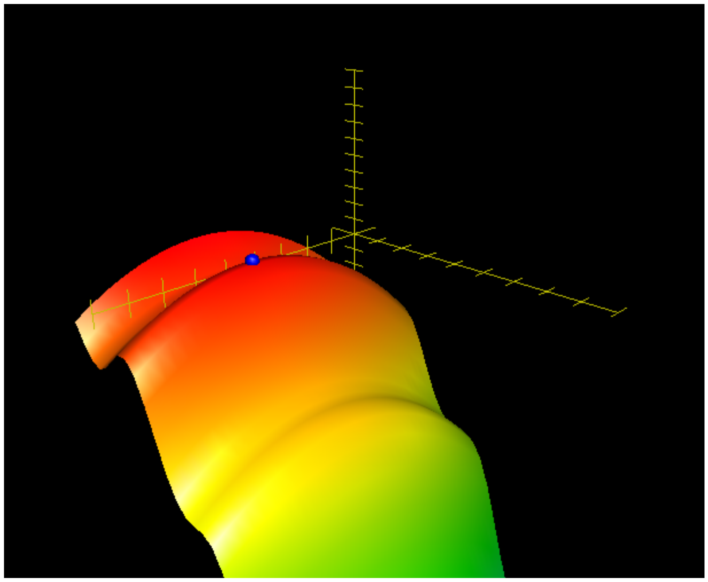

Figure 2. Maximum point of the graph f(x, y)

Calculus-based multivariable optimization shares many of the advantages of single-variable optimization, such as a high theoretical accuracy when used with accurately modeled production functions. Additionally, it has the obvious advantage of being able to optimize functions of several variables, in the form $f(x_1, x_2, x_3... x_n)$, which makes it particularly useful in applications such as crop growth, where each input has varying and largely independent effects on the final product. This can be connected to the multi-layer farming models, where we can find out the most impactful input and least important inputs by examining the results of optimization, which further allows us to eliminate or adjust factors that may be limiting yield. Suppose there is an equation which gives us greater yield when more water is used with less fertilizer, then we can conclude that the water is increasing productivity, which is our ultimate objective.

I embrace the fact that each farm can have different relationships with the variables used in the functions. So it is important to know that there is no single equation that could work for all the farms. If we have such an "ideal" equation, this would be the most theoretically efficient way of obtaining a maximized result, but it is not practical to expect every farm to have a clear and attainable production function.

Visualization, which involves graphing the function, makes understanding the problem at hand easier and gives us a clear idea of what is really happening in the function when we modify inputs as critical points can show us extreme changes in the concavity (upward or downward shape) of a graph. It is easy to graph and comprehend functions in 2D or 3D, but if a function involves four or more variables, it becomes immensely difficult to visually communicate changes in higher dimensions.

Like univariate optimization using calculus, we need to understand the relationship of every variable with another and form a production function accordingly before being able to maximize or minimize it. Therefore, this makes the multi-variable optimisation a less-likely to be used in agricultural sector and would not work well in the multilayer farming where many variables are used.

Machine Learning

As we all know, the advent of Artificial Intelligence(AI) has changed the computer's ability to process information and give us the output which were just imagined earlier. For example, Machine Learning, Natural Language Processing and Deep Learning which are subset of Artificial Intelligence have great advantages and are changing their usage and consequently the computer usage. ML is the approach to imitate human intelligence and reasoning power within computers which could add their ability to learn from empirical data by looking at the common trends and patterns in the problem.

In the agricultural context, especially in this paper, where production is taken as the major focus, machine learning-based optimization is a process through which the programs are able to predict the maximum and minimum point of a given problem. We can use existing empirical data to form highly accurate models for any given production scenario, using the calculus of gradient descent to find the "best-fit" model within a range of possibilities. Machine learning-based optimization algorithms help us make more informed decisions as they do not require an existing mapping of relations between various variables, as this is extracted from the data itself.

Machine learning-based support tools can provide a substantial impact on how production optimization is performed. If we talk about knowing the farming outputs and its production efficiency through a machine, it could be tedious and expensive to program, but also potentially very flexible and efficient. This requires a lot of data to gauge out the uniform pattern which can be used to get predictions about the future result.

However, many big data applications tend to create similar issues due to the lack of accountability in large-scale data processing. Black box problems are created directly from data of an algorithm where we cannot understand the precise nature of variables being combined to make predictions, even while knowing the algorithm itself. In machine learning, this is a serious problem. Due to almost no transparency in the process of finding the result, it can cause trust-issues with the program and can make removing systemic errors extremely difficult. Black Box problem could be a major obstacle for the program to explain to the farmers or other people, who do not have direct control over the optimization process.

Thus, optimization is a complex task to do as there are different parameters or variables included which affect the overall production in some or another way. Different applications would benefit variably from each of the given methods, and the ongoing development of ML processes will hopefully clear up many of the roadblocks in production-side optimization in the near future.

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