Computational Analysis of Corn Plant Growth, Growth Rate, and Acceleration Over Time

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Abstract

The above work provides a computer-based analysis of young corn plant development based on a time-dependent quadratic model, illustrating plant height, rate of growth, and acceleration of growth after appearance. The purpose of this study, as it is related to maize, is to demonstrate how simple models can be used in explaining the biological development process in an easy and educational way. The plant height measurements were performed in standard conditions three times after emergence in-order-to develop a quadratic model based on time elapsed after emergence as the independent variable. Plant height was determined under optimal conditions three times after germination to establish a quadratic function for plant growth with time since germination as the independent variable. Plant height was determined using this function, and acceleration and rate of growth were determined using its first and second derivatives, respectively. Findings showed that the initial growth of corn in plants follows a predictable function where plant height and rate of growth increased with time, while acceleration remained constant. Since the calculated values precisely corresponded to the actual values for the time points observed, model validation was achieved for the short observation period. Through forecasting the future growth rate of plant height over time, another piece of evidence of the potential of the quadratic function for short-term growth rate forecast can thus be noted, despite its failure to include variables such as soil or water nutrient content. Its findings have indicated the potential of time computation modeling for the analysis of the early growth rate of plants. This paper has shown how calculus models and basic mathematical techniques can be employed for the analysis of the growth rate of plants.

Keywords: corn growth, quadratic model, growth rate, growth acceleration, computational analysis

Introduction

Corn is one of the most important crops in the world, serving as a major source of food, livestock feed, and income for millions of people (FAO, 2023). Although some parameters, such as soil and water nutrient levels, were left out, the findings indicate that time computation modeling has been useful in the analysis of plant growth patterns in the early stages. This paper has clearly indicated that basic mathematical concepts and calculations in calculus can be applied in the analysis of plant growth patterns.

Researchers from all-across the world have long used plant growth measures to better understand crop development and productivity. Growth does not happen at a constant rate and is commonly observed as a rise in biomass or plant height (Taiz et al., 2015). Plants tend to grow slowly when young and then quickly as they mature. Due to this change in growth rate, many research papers employ mathematical models to more precisely and correctly describe plant growth (Jones et al., 2003). One basic idea used to analyze growth is growth rate, which is defined as the rate at which a plant is growing taller over a particular time interval (Hunt, 1990). The researcher can determine when the plants are developing at their fastest pace and when they begin to slow down by using growth rate analysis. Growth acceleration, which describes variations in the growth rate itself, is a similar growth concept. Growth acceleration indicates whether a plant's growth is increasing or decreasing with time, particularly during the plant's early phases of growth (Hatfield & Prueger, 2015). Using fundamental mathematical ideas, this method allows researchers to explain how growth varies across time. (López et al., 2017)

In the Philippines, corn is widely grown and is considered the second most important cereal crop next to rice (Bautista et al., 2019). More commonly studied regions for corn production research are those that involve agricultural practices, fertilizer use, and ways to increase production. Yet, instead of employing a quantitative or computational approach, farmers and agricultural programs within schools focus on observing plant growth (PhilRice, 2020). Whereas some local research focuses on the height of plants in different stages of development, none have explored further into the rate of plant growth and whether it is constant. Little effort has been put into local research using basic time-related models that could have explained the development of maize growth, although modeling plant growth has already been a proven concept worldwide. Most existing studies report plant height data without further analyzing growth rate and growth acceleration, which are important for understanding how growth develops over time. Moreover, the models of growth employed in various research studies are difficult to apply in the basic educational setting because of the complex equipment and software required. In reality, there is a lack of research work on the analysis of corn plant growth through the application of the basic quadratic equation in an understandable manner suitable to senior high school students.

The height of the plants is employed as an indicator of their growth in this study, which is focused on the analysis of corn plant growth during specified time intervals. Depending on time (3 days) since planting, this study applies a quadratic model to determine corn plant growth, rate of growth, and acceleration of growth. To ensure consistency in observations, data is collected from a few plants of maize grown under identical conditions. The entire life cycle of a maize plant is not taken into account in the study, which is carried out for a very short observation period. The computational part does not consider other variables such as temperature, pests, water, and soil nutrients that affect plant growth. Furthermore, this study uses a mathematical model rather than complex growth models or software-based simulations. Therefore, this mathematical model is not employed for large-scale farming growth simulations, but rather for fundamental and educational growth investigations.

This research intends to fill this gap by applying the quadratic model to examine the development and growth rate of corn plants over time. By applying a simple methodological approach using computers, this research intends to contribute to a better understanding of maize development dynamics which can be applied to both rural agriculture and educational settings.

Literature Review

In the Philippine setting, Bautista et al. (2019) have explored corn or corn plant or Zea mays L. growth and development, measuring plant height in equal time intervals after planting. Their study showed that there was an increasing trend in plant height, underscoring that measuring corn plant or Zea mays plant height within equal time intervals can be used to track plant development accurately over time. In a manner that is not primarily medical or economics-related, their study showed that there is potential in tracking plant development based on time data, starting from their study that utilized plant height data within specified equal time intervals. The findings are relevant, specifically in contexts such as farming or even school-based projects, where more specialized tools and equipment are not necessary, given that more specialized tools and equipment are not needed because larger data is not being processed and analyzed, rather more basic data that is still consistent and relevant in tracking plant development.

Based on this groundwork, Liang et al. in their research in 2024 demonstrated the ability to merge computing methods for maize plant development monitoring. In their research, they used both CNN models and time series forecasting models for automatic maize plant development stage recognition and forecasts for future development. In their research, it was made possible to classify plant development stages with clarity by applying detectable plant attributes for classification with accuracy. In this research, it has been clearly explained by Liang et al. in 2024 that by merging machine learning with time series data, it has been possible to capture minute variations in plant development patterns which are normally unnoticed during observation.

A study that is also relevant to this topic is that by Wardhani and Kusumastuti (2024), wherein they used non-linear mathematical functions, namely the logistic and Gompertz functions, to investigate the growing process of corn plant heights. This study showed that corn plants have a clear life cycle, wherein they grow slowly during the early part of their development, then grow very rapidly during their exponential phase, and finally stop growing altogether once they are almost mature. This study was able to accurately interpret plant height growth by correlating it to a mathematical function, and it shows that non-linear mathematical functions are proven more viable than linear functions in determining plant behavior because it more accurately interprets plant development and is able to provide deeper insight into plant development, including periods wherein plants slow down or speed up during the course of their life cycle.

In the same manner, N'Guessan and Emmanuel (2021) studied the usage of ANNs in predicting the growth variables of corn, including plant height and leaf area. The study made use of diverse variables like soil, temperature, and water, to name a few, to develop the model. The result of the experiment showed the efficiency of ANNs in predicting plant growth in an effective manner. However, the study emphasized the point of facilitated usage of computer-based solutions in the detection of acceleration in growth, as the measurement of acceleration in the natural manner is quite difficult to achieve. Based on the usage of time-series data in analyzing the model of the neural network, the authors supported the role of computer-based resources in learning the evolution of acceleration of growth in various phases of plant growth.

Peng et al. (2020) also examined research about maize plant height and growth simulations using computers. The authors were able to show through their research that growth rate and acceleration are very useful in understanding growth patterns in plants beyond mere measurements of plant height. The authors believe that growth rate and acceleration are very essential for optimizing practices such as irrigation and nutrient supply to plants growing at different stages depending on accurate identification of growth acceleration phases. The research examples continue to show how growth rate and acceleration are important tools in agriculture and can be applied for various uses depending on time and growth patterns measured from plants based on growth acceleration.

Li et al. (2019) conducted another international study in which maize growth was modeled at different environmental conditions using time-based height data. The research showed that the rate of growth does not remain constant during the growing season and may be affected, for example, by temperature, soil moisture, and sunlight. By using a mathematical model on the longitudinal data, the authors are able to show that temporal analysis has given a much clearer perception of the growth trend and stages of plants compared to simple visual inspection or individual measurement. This study could provide an important illustration of time-series data incorporated into plant growth studies and support the relevance of computational models by drawing valid predictions on plant development in different environmental conditions.

A study published in 2025 in BMC Plant Biology applied time-series remote sensing data for monitoring growth development of maize and the assessment of its relationship to yield outcomes. The leaf area, plant height, and biomass accumulation were tracked continuously throughout successive stages of development. Their study highlighted the fact that observing growth patterns in time is essential to correctly predict the productivity of a crop and thereby make proper agronomic decisions. Through temporal growth data on computational models, this study conveys the intrinsic requirement of time-based monitoring not just for research applications but also in practical agriculture management.

Lastly, a study titled "Modelling maize phenology and biomass growth under temperature variation" conducted in 2018 modeled the effects of temperature variation to understand how maize will react to these changes. This study proved that mathematical models have the ability to model growth rate, acceleration, and changes in phenology, hence enabling one to understand fully how changes affect plant growth. The study measured changes in growth acceleration and rate, hence creating a concept of how to measure reactions to different conditions for further extension of analysis of growth changes over time.

These works collectively underscore the increasing significance of mathematical and computational approaches to understanding the growth, rate of growth, and acceleration of corn over time. While international research is increasingly applying advanced modeling techniques, there remains a significant gap in the Philippine context, most especially in school-based and community-level initiatives. Most local studies still rely on ocular observation or simple descriptive data, largely without the use of accessible computational tools. Applying simpler models, such as the quadratic equation used in this study, allows for a practical and educational approach to understanding patterns in corn growth. By combining time-based measurements with computational modeling, students, researchers, and small-scale farmers can develop meaningful insights into plant development, growth rate dynamics, and acceleration patterns, which often are not available through traditional observation methods.

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Methodology

The design used for this study is quantitative and based on mathematical modeling, where the analysis is based on the model of the growth of the corn plant over time. This study aims to calculate the height, rate of growth, and acceleration of the growth of the corn plant based on the quadratic model of growth. This design enables the study to determine not only the height of the corn plant, but also the rate at which it grows and the acceleration of the rate of growth.

1. Time Frame and Growth Assumption

Corn seeds do not immediately exhibit height growth after planting due to the germination phase. Based on agricultural observations, visible growth typically begins three days after planting. Therefore, this study defines time as:

$\boldsymbol{t}$ = *number of days after plant emergence*

The day of emergence (*Day 3 after planting*) is assigned as t = 0. This ensures that the model reflects actual biological growth rather than seed dormancy.

2. Mathematical Model

The growth of the corn plant is represented by the quadratic function:

$$\boxed{\boldsymbol{G_p(t) = G_a t^2 + G_e t + G_o}}$$

Where:

$\boldsymbol{G_p}$= plant height at time(t)(cm)
$\boldsymbol{G_a}$= growth acceleration constant (growth pattern)

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G_e= early growth rate (cm/day)
G_o= initial height at emergence (cm)
t = days after emergence

Variable

1. Independent Variable

   1.1 Time (t) – measured in days after emergence.

2. Dependent Variable

   2.1 Plant Growth (G_p) – height of the corn plant in centimeters.

3. Growth Constants

   3.1 Initial Growth (G_o) – height of the corn plant at t = 0
   3.2 Early Growth Rate (G_e) – rate of growth immediately after emergence
   3.3 Growth Acceleration (G_a) – indicates how the growth rate changes over time.

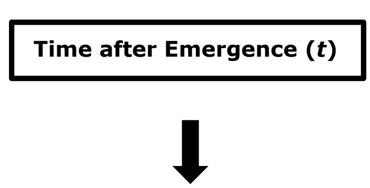
Procedure

1. Data Collection
2. Mathematical Model
3. Documentation

Conceptual Framework

This study is based on the idea that plant growth occurs over time and can be explained using mathematical models. As a corn plant develops, its height increases gradually, and the speed of this growth may change at different stages of development. In this study, time after emergence ***(t)*** serves as the main independent variable because it influences important physiological processes such as cell division, cell elongation, and nutrient absorption, all of which contribute to the increase in plant height. As time progresses, these biological processes result in observable plant growth, measured as plant height ***(G_p)***, which is the dependent variable of the study. To clearly describe how growth changes over time, a quadratic function is used to represent not only the increase in height but also the acceleration of growth. The framework also includes key growth parameters: initial growth ***(G_0)***, which represents the plant's height at emergence; early growth rate ***(G_e)***, which describes how fast the plant grows shortly after emergence; and growth acceleration ***(G_a)***, which explains how the growth rate changes over time. Together, these parameters allow the study to move beyond simple measurement and provide a deeper understanding of plant growth by analyzing both growth rate and acceleration using basic mathematical techniques.

Diagram 1.0



Plant Growth Model

$$G_p(t) = G_a t^2 + G_e t + G_o$$

↓

Computed Outputs

- Plant Height (G_p)
- Growth Rate ($G_p'(t)$)
- Growth Acceleration ($G_p''(t)$)

↓

Growth Interpretation and Prediction

Results

Three post-emergence data points were used by the researcher to determine the growth constants.To ensure biological realism, the researcher set a growth boundary condition or time interval:

$$0 \leq t \leq T_{max}$$

where T_{max} represents the time before growth start to slow or stop.

Table 1. Observed Corn Plant Height After Emergence

Day After Emergence(t)	Actual Day	Plant Height($G_p t$)
0	Day 3	1.5 cm
1	Day 4	2.8 cm
2	Day 5	4.6 cm

Using the model:

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$$G_p(t) = G_a t^2 + G_e t + G_o$$

Step 1: Solve for G_o (initial height at emergence (cm)) at time(t)=0

$$G_p(t) = G_a t^2 + G_e t + G_o$$
$$G_p(0) = G_a(0)^2 + G_e(0) + G_o$$
$$G_p(0) = G_o$$
$$G_p(0) = 1.5 \text{ cm} \longrightarrow \textit{Initial Growth}$$

Step 2: Form equations using the remaining data at time(t)=1

$$G_p(t) = G_a t^2 + G_e t + G_o$$
$$G_p(1) = G_a(1)^2 + G_e(1) + G_o$$
$$G_p(1) = G_a + G_e + G_o$$
$$2.8 \text{ cm} = G_a + G_e + 1.5 \text{ cm}$$
$$G_a + G_e = 2.8 \text{ cm} - 1.5 \text{ cm}$$
$$G_a + G_e = 1.3 \text{ cm} \longrightarrow \text{Equation 1}$$

At time(t)=2,

$$G_p(t) = G_a t^2 + G_e t + G_o$$
$$G_p(2) = G_a(2)^2 + G_e(2) + G_o$$
$$4.6 \text{ cm} = 4G_a + 2G_e + 1.5 \text{ cm}$$
$$4G_a + 2G_e = 4.6 \text{ cm} - 1.5 \text{ cm}$$
$$4G_a + 2G_e = 3.1 \text{ cm} \longrightarrow \text{Equation 2}$$

Step 3: Solve the system

Multiply the first equation by 2.

$$2(G_a + G_e = 1.3 \text{ cm})$$
$$2G_a + 2G_e = 2.6 \text{ cm}$$

Subtract the equation 1 to equation 2.

$$\begin{array}{rl} & 4G_a + 2G_e = 3.1 \text{ cm} \\ - & 2G_a + 2G_e = 2.6 \text{ cm} \\ \hline & 2G_a = 0.5 \text{ cm} \end{array}$$

$$\frac{2G_a = 0.5 \text{ cm}}{2}$$

$$G_a = 0.25 \text{ cm} \longrightarrow \textit{Growth Acceleration}$$

Substitute back to the equation 1,

$$G_a + G_e = 1.3 \text{ cm}$$
$$0.25 \text{ cm} + G_e = 1.3 \text{ cm}$$

$$\boldsymbol{G_e} = 1.3\text{ cm} - 0.25\text{ cm}$$
$$\boldsymbol{G_e} = 1.05\text{ cm} \longrightarrow \textit{Early Growth Rate}$$

Therefore, the final growth model is presented by:

$$\boldsymbol{G_p(t)} = 0.25\,\boldsymbol{t}^2 + 1.05\boldsymbol{t} + 1.5$$

To get the height of the corn plant at time(t)=0, time(t)=1 and time(t)=2 using the plant growth function ($\boldsymbol{G_p{}'(t)}$), we will simply substitute the time(t) in the function. So if we calculate the height of the corn plant at time(t)=2 :

$$\boldsymbol{G_p(t)} = 0.25\,\boldsymbol{t}^2 + 1.05\boldsymbol{t} + 1.5$$
$$\boldsymbol{G_p(2)} = 0.25(2)^2 + 1.05(2) + 1.5$$
$$\boldsymbol{G_p(2)} = 4.6\text{cm}$$

Therefore, the height of the corn plant at time(t)=2 is equal to 4.6cm and matches the height used in the data.

To calculate the growth rate (cm/day), we will find the first derivative of the plant height function ($\boldsymbol{G_p{}'(t)}$) which is also equal to the change in height over the change in time.

$$\boldsymbol{G_p(t)} = 0.25\,\boldsymbol{t}^2 + 1.05\boldsymbol{t} + 1.5$$
$$\boldsymbol{G_p{}'(t)} = \frac{dG_p}{dt} = 0.5\boldsymbol{t} + 1.05$$

So to calculate the growth rate at time(t)=2,

$$\boldsymbol{G_p{}'(2)} = \frac{dG_p}{dt} = 0.5(\boldsymbol{2}) + 1.05$$
$$\boldsymbol{G_p{}'(2)} = \frac{dG_p}{dt} = 2.05\ cm/day$$

Therefore, the growth rate at time(t)=2 is equal to 2.05 cm/day.

So to calculate the growth acceleration (cm/day^2), we will find the second derivative of the plant height function ($\boldsymbol{G_p{}'(t)}$) which is equal to the change in growth rate over the change in time.

$$\boldsymbol{G_p{}'(t)} = \frac{dG_p}{dt} = 0.5\boldsymbol{t} + 1.05$$
$$\boldsymbol{G_p{}''(t)} = \frac{d^2G_p}{dt} = 0.5\ cm/day^2$$

So, the acceleration at any given time is equal to 0.5 cm/day^2.

Table 2. Calculated Plant Height, Growth Rate and Growth Acceleration Over time

Day After Emergence(t)	Actual Day	Plant Height ($G_p(t)$)	Growth Rate ($G_p{}'(t)$)	Growth Acceleration $G_p{}''(t)$
0	Day 3	1.5cm	1.5 cm/day	0.5 cm/day^2
1	Day 4	2.8cm	2 cm/day	0.5 cm/day^2
2	Day 5	4.6cm	2.05 cm/day	0.5 cm/day^2

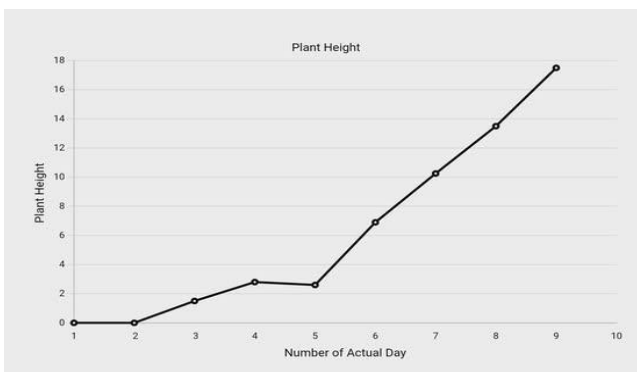
Using the plant growth function model $G_p(t) = 0.25\,t^2 + 1.05t + 1.5$, calculated from the thre-post emergence data point at a given time. Using this model, the researcher will able to calculate the future height, growth rate and growth acceleration of plant corn at given time.

Table 3. Prediction Future Plant Height, Growth Rate and Growth Acceleration Over time

Day After Emergence(t)	Actual Day	Plant Height ($G_p(t)$)	Growth Rate ($G_p{}'(t)$)	Growth Acceleration $G_p{}''(t)$
0	Day 3	1.5cm	1.5 cm/day	0.5 cm/day^2
1	Day 4	2.8cm	1.55cm/day	0.5 cm/day^2
2	Day 5	4.6cm	2.05 cm/day	0.5 cm/day^2
3	Day 6	6.9cm	3 cm/day	0.5 cm/day^2
4	Day 7	7.5cm	3.5cm/day	0.5 cm/day^2
5	Day 8	10.25cm	4cm/day	0.5 cm/day^2
6	Day 9	13.5cm	4.5cm/day	0.5 cm/day^2
7	Day 10	17.5cm	5cm/day	0.5 cm/day^2

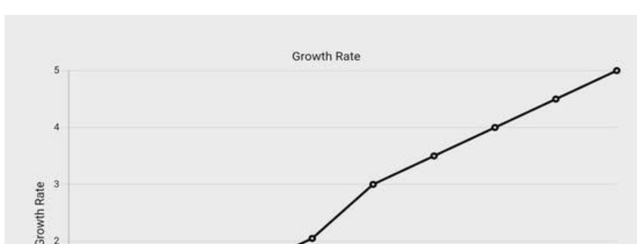
Based on the result in predicting the possible future height of the plant corn, growth rate and growth acceleration at a given time. We can see that there is an increasing height and growth rate of the plant corn while having a constant acceleration.

Graph 1. Plant Height at a Given Time

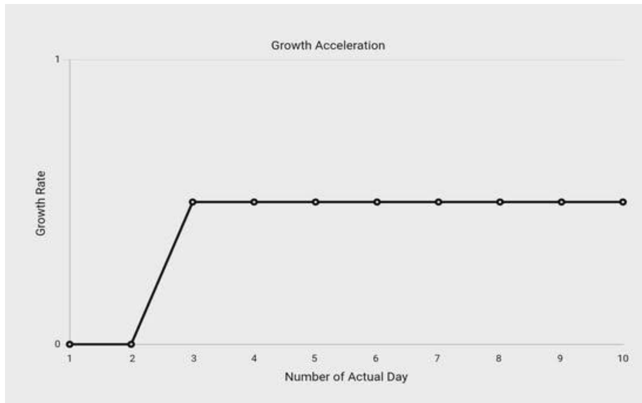


Graph 2. Plant Growth Rate at a Given Time

Graph 2. Plant Growth Rate at a Given Time



Graph 3. Plant Growth Acceleration at a Given Time



Discussion

The methodology of this research is to describe the growth of corn plants in an understandable and organized manner by employing mathematical models. Model method was chosen for this research because it is possible to measure the growth of plants because it is not constant and it can be quantified. The central idea that "time is the most fundamental environmental factor controlling plant growth and determines development and physiological processes such as cell division and extension" is valid because the independent variable is $\mathbf{t}$ and the dependent variable is $\boldsymbol{G_p}(\mathbf{t})$ (Hunt, 1990; Taiz et al., 2015). The quadratic growth model can be utilized in the simulation of corn growth at the early stage since the corn does not grow at a constant rate at the early stage of growth. There is general knowledge that the corn plant normally grows at a very slow rate at the early stage of growth before accelerating. According to a study carried out by López et al. (2017), the quadratic models can be applicable in the determination of corn growth at the early stage of development with regard to the increase in the height of the plants, as well as the determination of the growth rate. In comparison to other models, such as crop models or artificial neural networks, the current quadratic model is quite simple. Additionally, the model points out some features of plant growth that make it easy to interpret the growth of the plant. The early stages of plant growth $(\boldsymbol{G_0})$ indicate the height of the plant during the early stages of emerging, the early stages of plant growth $(\boldsymbol{G_e})$ indicate the rate of growth during the early stages of emerging, while the acceleration of plant growth $(\boldsymbol{G_a})$ indicates the increase or decrease in the rate of plant growth. Growth can be measured for height and for further interpretation of plant dynamics. The first and second derivatives have been widely used for identifying rates of plant growth (Hunt, 1990; Hatfield & Prueger, 2015). To validate the quadratic model, calculations were performed for plant height, which were then compared with the actual measured plant height for $\mathbf{t}$=0, 1, and 2. Since the points accurately match, it can be stated that this model is applicable for describing maize plant development during a restricted period. Validation of similar models can be observed in previous studies on growth modeling, wherein the accuracy of the model depends on how well it predicts actual data points. This shows consistency in suggesting that this model is both mathematically and biologically correct for short-term growth modeling. The capability to predict outcomes further enhances this model's usability. The quadratic equation applied in this study was applied to predict future plant height, growth, and acceleration. From the past studies, it was observed that the growth rate of the corn is faster during the initial phase of the vegetative growth stage (Peng et al., 2020). The result showed that the height of the plants, along with the growth rate, would increase further at a faster pace. The predictions reveal that the future growth trends can be estimated through the application of the simplest mathematical models, even though they are incorrect due to the shorter duration of the data and the lack of environmental factors. The technique adopted in the experiment, through the combination of the simplicity of the mathematical models and the convenience of data gathering, plays a crucial role in achieving the goals of the research. This experiment did not consider any environmental variables, like soil nutrients, water, or temperature, to clearly illustrate how time affects plant growth. This simple experiment can be replicated in a class. Further studies have shown that simple models for plant growth can be useful for teaching purposes, even if advanced technology is not available (Bautista et al., 2019; PhilRice, 2020). Further studies can be conducted to better represent real-world conditions for plant growth.

Conclusion

The result obtained from the experiment shows that the growth of the corn plant after germination can be modeled using a simple formula in relation to time. This formula, which was obtained from a quadratic equation, made it possible to calculate the height of the plant, rate of growth, and rate of change in growth rate. This means that the rate of growth of corn plants at their initial stages of growth can be predicted and is in line with standard plant growth principles. This means that simple algebra can be employed to understand certain processes in nature, including plant growth. The entire community, including students, teachers, and small farm owners, shall benefit from the results of this study. This project shall provide teachers and students with the opportunity to relate science and mathematics using practical examples. The growth model can be applied to school gardens as well as small farm gardeners to measure growth and ensure that maize plants are growing as they should. Studies have shown that knowledge of growth patterns can aid in agricultural decision-making as well as effective crop monitoring. The matter of depending on human sight to verify growth shall also be solved in this research. The growth of the plants can be measured accurately through the mathematical approach. The approach can also be utilized for the comparison of the growth of the plants over time. This will also aid in the identification of the growth patterns that are irregular, associated with either nutritional or water shortages, through the approach. The idea that the irregular growth patterns can be utilized for improving the growth of the plants, preventing possible losses, is justified through research. From the findings, it is recommended that basic models of plant growth should be taught in community farming and institutions of learning. This will enable teachers to impart information to students concerning arithmetic and botany using the same model. On the other hand, the general public will also be able to monitor the early growth of the plants using basic models of plant growth. In view of this research work, it can be understood how crucial mathematical modeling is in comprehending corn plant germination. This shows how efficient the time function is in modeling to yield meaningful results in plant growth, regardless of whether it only tackles the initial stages of corn plant germination and disregards environmental aspects. However, in the future, other aspects such as temperature, water, and soil quality may be included to yield more precise results

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