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Forecasting Technology Adoption Behaviour and Agricultural Production Growth

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ABSTRACT

In this paper, we proposed a simple mathematical model for farmers in the Ranchi district to adopt and implement agricultural technologies. We used the Fisher-Pry model, which is a very effective model in the study of technological adoption. The model's output is a Sigmoid curve, or S-shaped curve, that develops exponentially at first, then approximately linearly, and lastly asymptotically. We have studied the models of technology spread using a basic case study and brought in a real-world situation. Mathematically, it is possible to predict that adoption will rise to the number m/2 implies when 50% of the farmers have adopted the technology, after which it will slow down. In a real-life situation, the point of inflection might occur before or after m/2.We also collected data on some of the food crops, net irrigated area of Ranchi district from 2011 to 2020, and evaluated it graphically/mathematically. We examined the advantages of technology in agriculture using utility functions, by employing basic scenarios and selecting between different technologies for adoption

KEYWORDS: Agriculture, Technology, Forecast, Adoption, Mathematical Modeling.

I. INTRODUCTION

Agriculture is the main source of income in Jharkhand, accounting for 60-75 percent of the population. Farmers in this region are uninformed of and uninterested in newer and better agricultural technology, resulting in low production. As a result, they have become underprivileged.New agricultural technology has the potential to increase the production and quality of agricultural goods, as well as improve people's economic conditions. Farmers using new information to cultivation methods and other agricultural activities in order to increase production and quality. By replacing the old style of farming with a new and more effective method of agriculture, the region may benefit from technological innovation.The following were some of the main obstacles in the way of farmers in the research area adopting new agricultural technology[1]:

1. Agricultural activities are frequently delayed due to a lack of appropriate and timely assured irrigation facilities.
2. To increase productivity, the technical input has got to be reoriented and reinforced.
3. Due to its growing preference for nuclear families and young migration to urban areas for the glamorous city life, there is a shortage of manpower in the household.
4. For a good price, there were insufficient marketing facilities.
5. The region's educated young, in particular, have lost interest in agriculture.

The elements of technology diffusion comprise of innovation, strategies to commercialize technologies is propagation, time, and units of social system[2].In view of this, we investigated a mathematical model for predicting new agricultural technology adoption among farmers of the Ranchi district in this paper. Here, we have predicted that the adoption process of agricultural technologies as S-shaped curve or sigmoid pattern growth, the adoption goes through phases which includes initial exponential phase, an approximately linear phase and finally an asymptotic phase

II. NOTATIONS

m: Total no. of farmers.

y(t)	:No. Of farmers who are using technology in time t.
N, P, K	:Nitrogen, Phosphors, Potassium.
U(x)	:Overall utility of the technology option x.
α_1, α_2	: weighting factors representing the importance of performance and price respectively.
WAUF	:Weighted arithmetic utility function.
WGUF	:Weighted Geometric Utility function.
WHUF	:Weighted Harmonic Utility Function.

III. MATHEMATICAL MODELING

Let us suppose that m be the total number of farmers. Also, let $y(t)$ be number of farmers who have adopted the new technologies in time t. Also a farmer will adopt the new technology only after a farmer who already uses it told him about it.

Let us suppose that δy farmers adopt the new technologies in time δt. At any time t, let $y(t)$ be the number of farmers who are using technology and $\{m - y(t)\}$ be the number of farmers who are not using technology.

Therefore, $\delta y \propto y(t)$

$\delta y \propto \{m - y(t)\}$

$\delta y = Cy(t)\{m - y(t)\}\delta t$

Where, C is the positive constant.

If the number of successful adopters, who can communicate the new innovation in efficient manner, is large, the greater will be the number who can possibly adopt it and larger will be the rate of change $y(t)$. So that we assume [3]

$$\frac{dy}{dt} = Cy(t)\{m - y(t)\} \qquad (1)$$

This gives the first mathematical model.

On solving, we have

$$log\left|\frac{y}{m-y}\right| = mCt + A$$

Where,A is the integration constant which can be calculated after taking initial conditions.

If at $t = 0; m = m_0$ & $y = y_0$,value of the above equation

$$log\left|\frac{y}{m-y}\right| = mCt + log\left|\frac{y_0}{m_0 - y_0}\right|$$

But if $y_0 = 1$, we have

$$y = \frac{me^{mCt}}{m_0 - 1 + e^{mCt}}$$

Let $\frac{y(t)}{m} = f(t)$

Then (1) reduces to

$$\frac{df(t)}{dt} = C_1 f(t)[1 - f(t)] \qquad (2)$$

We investigate this model

Since $y(t) \le m, f(t) \le 1, \frac{df(t)}{dt} \ge 0$

$$\frac{d^2f}{dt^2} = C_1\{1 - 2f(t)\}\frac{df(t)}{dt}$$

Now,

$$\frac{d^2f}{dt^2} > 0 \; for \; f(t) < \frac{1}{2}$$

$$\frac{d^2f}{dt^2} = 0 \; for \; f(t) = \frac{1}{2}$$

$$\frac{d^2f}{dt^2} < 0 \; for \; f(t) > \frac{1}{2}$$

Also, $\frac{df(t)}{dt}$ increases when $f < \frac{1}{2}$ and decreases when $f > \frac{1}{2}$

$f(t)$ or $y(t)$ increases at increasing rate when $y(t) < \frac{m}{2}$ and it increases but at decreasing rate $y(t) > \frac{m}{2}$.

There is a point of inflection when $f(t) = \frac{1}{2} \; or \; y(t) = \frac{m}{2}$

On solving (2),

$$f(t)\{1 - f_0\} = f_0\{1 - f(t)\}e^{C_1 t}$$

$$f(t) = \frac{1}{1 + \frac{1 - f_0}{f_0}e^{-C_1 t}}$$

Where f_0 is the value of $f(t)$ at $t = 0$.

Thus $f(t) \le 1$ and $f(t) \to 1$, when $t \to \infty$

$y(t) \to m$ when $t \to \infty$

That is the technology will have to wait a long time for all farmers to adopt it. In today's continuously emerging technology age, adopters have the ability to adopt new technologies at any time, therefore previous ones will not be adopted by all farmers.

The model (2) is called Fisher-Pry model [4] and is a very successful model for explaining how, why, and how quickly new ideas and technologies spread

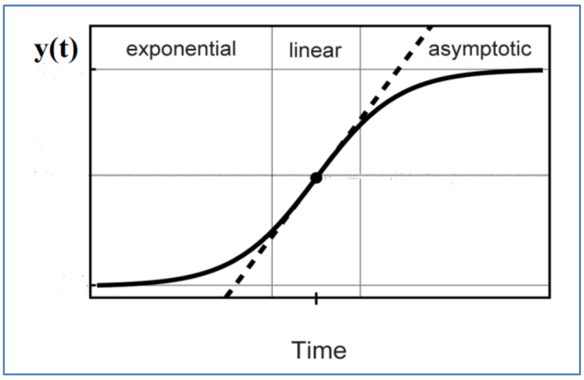

Figure 1: Sigmoid curve

IV. VERIFICATION OF MATHEMATICAL MODEL

In Ranchi, farmers have significantly enhanced their agricultural practices by adopting new technologies. They have upgraded their irrigation systems, incorporated various technological advancements, and improved their overall farming efficiency.These advancements aim to increase food production efficiency and yield. To ensure our mathematical model accurately represents these changes and their impact on crop yields, we have conducted a thorough verification process. We have looked closely at the data to understand these changes and how they are happening on the ground.

a) Yield(in Tonnes/Hectare) of some major food crops (rice, wheat maize, Ragi) grown in Ranchi District

Table 1: Yield of some major food grains of Ranchi District

Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Yield(Rice)	-	1.73	1.67	1.56	1.74	0.53	2.43	2.40	2.40	3.24
Yield(Wheat)	1.48	2.04	2.06	2.31	2.09	1.74	2.24	2.00	0.42	2.00
Yield(Maize)	-	2.34	3.09	2.91	2.77	1.36	3.42	2.51	2.36	2.75
Yield(Ragi)	-	1.23	1.15	0.78	0.84	0.48	0.98	0.75	0.75	0.81

Graph as per above data and forecast given below

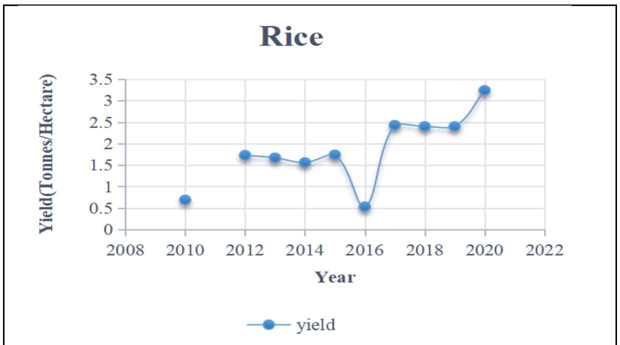

Figure :2

Comparision with sigmoid curve:

Initial Phase (2011-2014): The yields show a gradual decline, which doesn't align perfectly with the typical slow increase of the initial phase of a sigmoid curve but indicates a variability or instability.

Middle Phase (2015-2018): After a dip in 2016, there is a rapid recovery and stabilization in the yields (2017-2019), which is somewhat analogous to the rapid growth phase in the sigmoid pattern.

Final Phase (2019-2020): The yield jumps significantly in 2020, which resembles the leveling off or reaching a higher stable state seen in the final phase of a sigmoid curve.

The overall trend from 2015 to 2020 exhibits a quick recovery and stabilization, which may be connected to the growth and leveling phases of a sigmoid pattern, even though the first decrease in yields deviates from a normal sigmoid start. This shows that agricultural techniques or environmental circumstances improved greatly despite the early fluctuation, resulting in a more stable and greater yield that is consistent with the latter phases of a sigmoid curve.

Prediction: To forecast the rice yield for the years 2021, 2022, 2023, 2024 and 2025 in a sigmoid pattern, we need to fit a sigmoid function to the given data. The sigmoid function is generally defined as [5]:

$$Y(t) = \frac{L}{1 + e^{-k(t-t_0)}}$$

Where, Y(t) = yield at time t.

L= maximum value of the curve.

K= growth rate.

t_0= midpoint of the sigmoid curve(the time at which the yield is at half its max.)

We choose the values of the parameters L, k and t_0 to minimize the gap between the sigmoid curve and the real data.

$L \approx 3.5, k \approx 0.7, t_0 \approx 2018$

For the years 2021, 2022, 2023, 2024 the approximate predicted yield are nearly equal to 2.98, 3.12, 3.20, 3.25,3.48, 3.49(in Tonnes/hectare)

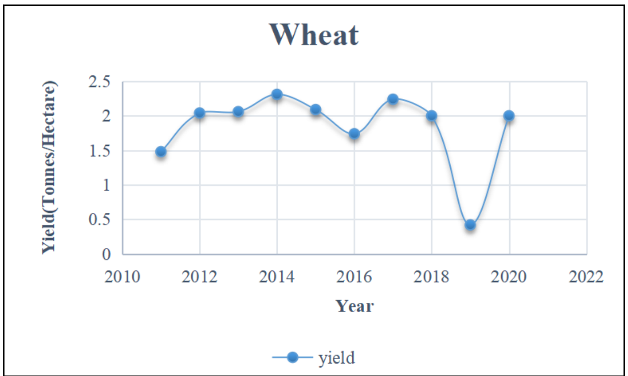

Figure:3

Comparison with a Sigmoid Curve:

Initial Phase(2011-2013): This phase shows an increase in yield, which is consistent with the initial slow growth phase of a sigmoid curve.

Middle Phase(2014-2017): The yield peaks and then fluctuates, which could be seen as a rapid growth phase followed by stabilization.

Later Phase(2018-2020): The yield shows a significant drop and recovery, which is less typical of a sigmoid curve but could suggest external disruptions.

The wheat yield data exhibits a sigmoid curve-like pattern for the first and middle stages, but the interruption in 2019 points to an abnormality. Despite this, the general trend exhibits the characteristics of a sigmoid pattern, including early increase, stability, and a recovery phase, however, some deviations are probably caused by outside variables influencing wheat output.

Prediction:

For wheat we choose the values of parameters L, k, t_0 as

$$L \approx 2.5, k \approx 0.6, t_0 \approx 2015$$

The approximate yield prediction for the years 2021,2022,2023,2024 and 2025 are 2.18, 2.32, 2.41, 2.45, 2.49(in Tonnes/ Hectare)

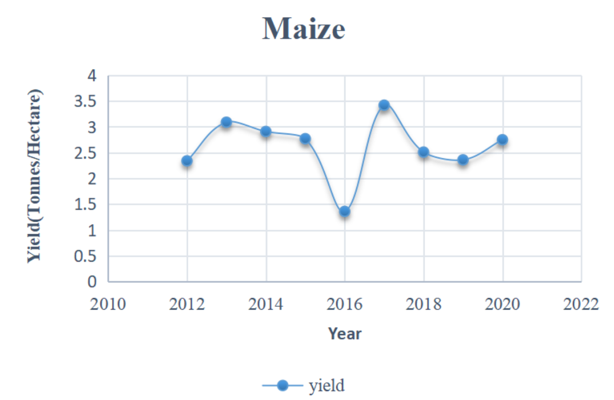

Figure:4

Comparison with a Sigmoid Curve:

Initial Phase(2011-2013): The increase from 2012 to 2013 fits the early growth phase of a sigmoid curve.

Middle Phase(2014-2017): The fluctuations and significant drop in 2016, followed by a rise, resemble instability but can still be viewed as part of the growth phase, though with external perturbations.

Later Phase(2018-2020): The stabilization from 2018 to 2020 aligns with the leveling off phase of a sigmoid curve.

The maize yield data shows a trend that can be compared to a sigmoid curve, with some deviations. Despite the fluctuations in the middle phase, the overall pattern reflects an initial increase, a period of instability (which could be influenced by external factors), and eventual stabilization, broadly following a sigmoid trend.

Prediction: For Maize we choose the values of parameters L, k, t_0 as

$$L \approx 3.42, k \approx 0.5, t_0 \approx 2015$$

The approximate yield prediction for the years 2021,2022,2023,2024 and 2025 are 3.26, 3.36, 3.40, 3.41,3.42(in Tonnes/ Hectare)

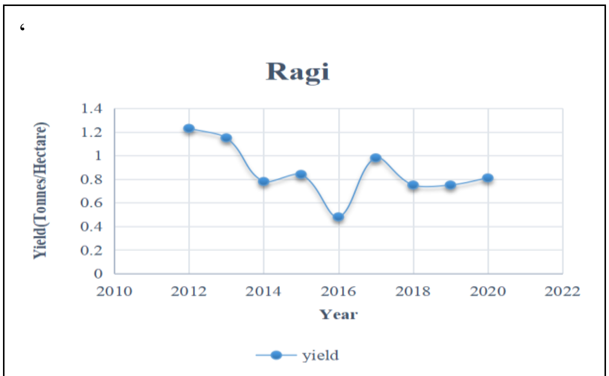

Figure:5

Comparison with a Sigmoid Curve:

Initial Phase(2011-2013): The initial data shows a decline, which doesn't fit the typical early growth phase of a sigmoid curve.

Middle Phase(2014-2017): The yield experiences significant fluctuations and a recovery, which indicates instability rather than a steady growth phase.

Later Phase(2018-2020): The yield stabilizes in the later years, aligning with the leveling off phase of a sigmoid curve.

Although the ragi yield data does not perfectly follow a sigmoid pattern, especially in the initial phase, it eventually reaches a more stable state in the later years. The significant fluctuations in the middle years suggest external factors heavily influenced the yield, preventing a smooth sigmoid curve progression.

Prediction: For Ragi we choose the values of parameters L, k, t_0 as

$$L \approx 1.23, k \approx 0.5, t_0 \approx 2014$$

The approximate yield prediction for the years 2021,2022,2023,2024 and 2025 are 1.21, 1.22, 1.22, 1.23, 1.23(in Tonnes/ Hectare)

b) Irrigation by various methods

Table 2: Net irrigated area(in ha) in Ranchi District.

year	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18	2018-19	2019-20	2020-21
Tank	1198	1884	1662	1719	1496	10362	5247	7862	8168	7385
well	9890	12853	10634	10794	9929	14785	8859	12915	11694	9676
other	2817	3857	3160	3607	2509	8753	2692	5010	4685	5083

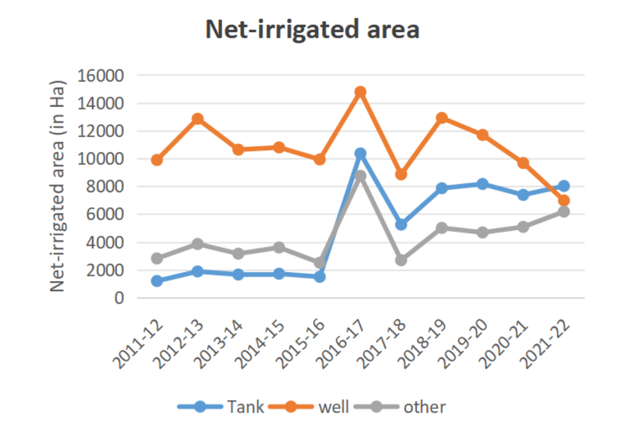

Figure:6

The tank data for somewhat resembles a sigmoid curve with an initial low phase, rapid growth, and then a decline. For well, the curve has a less noticeable curvature and resembles a sigmoid with a gradual increase followed by a point of stability. For others, this curve shows less resemblance to a sigmoid, but still exhibits some initial growth and then stabilization.

c) Consumption of chemical fertilizers(N,P,K)

Table 3: Yearly consumption of N,P,K

Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
N,P,K	79.080	118.02	111.83	82.48	91.80	122.84	114.51	92.53	127.09	131.90

Initial phase(2011-2012): The value of N, P, K increased significantly from 79.08 in 2011 to 118.02 in 2012. This steep increase suggests an initial adoption of new agricultural technologies and practices, leading to a substantial rise in nutrient use.

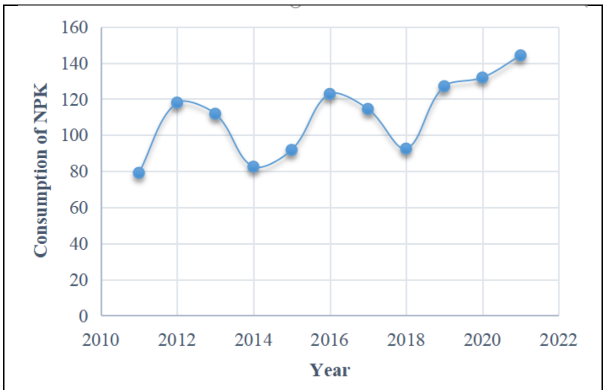

Figure:7

Growth phase(2012-2017): From 2012 to 2013, there is a slight drop in N, P, K values to 111.83, followed by another drop to 82.48 in 2014. This indicates some variability or challenges in sustaining the initial growth.

However, from 2014 to 2016, the values show another increase from 82.48 to 122.84. This period captures a second wave of adoption or improvement in practices, entering a phase of rapid growth overall despite yearly fluctuations.

Later phase(2017-2020):From 2017 onwards, the N, P, K values still fluctuate but generally continue to increase, though at a slower rate. The values go from 114.51 in 2017 to 131.90 in 2020.

This trend suggests the system is approaching saturation, where the rate of increase slows down, indicative of the later phase of the sigmoid curve where maximum efficiency or near-optimal usage is being approached.

This analysis helps in understanding how technological adoption impacts agricultural practices over time, reflecting a typical S-shaped growth curve.

To understand the factors influencing technology adoption in agriculture several utility functions have been developed

Assume that $n_1, n_2, n_3, \ldots, n_k, k \geq 2$, are the technologies available for adoption. The following formula can be used to calculate the benefits of using new technologies:

1. Direct Evaluation: Here the overall benefit is evaluated in the combined form $U(n_1, n_2, n_3, \ldots, n_k)$ using all the technologies under consideration.

We consider a simplified example of using a utility function to evaluate the adoption of a new technology, such as technology upgrade. We consider a basic utility function and then apply it to two different technology options: Option A and Option B.

Utility Function Construction: we used a linear utility function for simplicity.

$$U(x) = \alpha_1.\text{Performance}(x) + \alpha_2.\text{Price}(x)$$

Where, U(x) represents overall utility of the technology option x.

Performance(x) represents the performance of the technology x.

Price(x) represents the price of the technology option x.

α_1 and α_2 are weighting factors representing the importance of performance and price respectively.

Let us consider for available technology option A.

Performance(A) =8 (on a scale of 1-10, where higher is better), Price(A) = 800 and for the technology option B, Performance(B)= 7, Price(B) = 700

We also assume weighting factors $\alpha_1 = 0.7$ and $\alpha_2 = -0.3$, indicating that performance is more important than price, but there is a negative impact of price on utility.

For the technology A:

$$U(A) = 0.7 \times 8 + (-0.3) \times 800 = -234.4$$

For the technology B:

$$U(B) = 0.7 \times 7 + (-0.3) \times 700 = -205.1$$

On comparing the results we find that option A has higher utility value compared to option B according to our utility function. Therefore, based on this evaluation option A would be preferred over option B. This simplified example demonstrates how a utility function can be used to directly evaluate and compare different options based on relevant attributes. In practice, more complex utility functions with additional attributes and factors could be used to provide a more comprehensive evaluation.

2. Decay Evaluation: Using the individual benefit of all the available technologies $U_i(n_i)$, computed $U(n_1, n_2, n_3, \ldots, n_k)$ by combining the $U_i(n_i)$ of all the technologies in different manner[6].

Three models were used and discussed below: WAUF, WGUF, and WHUF.

i. Weighted arithmetic utility function (WAUF)

$$U(n_1, n_2, n_3, \ldots, n_k) = w_1U_1(n_1) + w_2U_2(n_2) + \ldots + w_kU_k(n_k)$$

$$= \sum_{i=1}^{k} w_iU_i(n_i),\ 0 \leq U_i(n_i) \leq 1,$$

$$\sum_{i=1}^{k} w_i = 1, 0 \leq w_i \leq 1$$

Probably the most popular and extensively used version is the one above. The utility function for each technology is multiplied by the importance given to it, and the overall score for all the technologies is then calculated by adding together all of these products.

Here, $U(n_1, n_2, n_3, \ldots, n_k)$ represents the overall utility of the available options $n_1, n_2, n_3, \ldots, n_k$.

w_i represents the weight assigned to attribute i. These weights reflect the relative importance of each attribute in the decision-making process.

$U_i(n_i)$ represents the value of attribute n_i for option i. n represents the total number of attributes considered.

Let us consider an example where we evaluate two technology available for agriculture based on their performance, price and device with technology.

We assign weights w_i to each attribute based on their importance in decision making process.

Let performance $w_1 = 0.5$, Price $w_2 = -0.3$, Device with technology $w_3 = 0.4$

For technology A, Performance(A) = 8, Price(A)= 800, Device with technology(A) = 9

$U(A) = 0.5 \times 8 + (-0.3) \times 800 + 0.4 \times 9 = -232$

For technology B, Performance(B)=7, Price(B)= 700 , Device with technology(B)= 8

$U(B) = 0.5 \times 7 + (-0.3) \times 700 + 0.4 \times 8 = -203.3$

Therefore technology A has a higher utility value compared to technology B according to our utility function

ii. Weighted Geometric Utility function(WGUF)

$$U(n_1, n_2, n_3, \ldots, n_k) = U_1(n_1)^{w_1}.U_2(n_2)^{w_2} \ldots U_k(n_k)^{w_k} = \prod_{i=1}^{k} U_i(n_i)^{w_i}, 0 \le U_i(n_i) \le 1,$$

$$\sum_{i=1}^{k} w_i = 1, 0 \le w_i \le 1$$

In this case, the technologies are combined into a product.

iii. Weighted Harmonic Utility Function(WHUF)

$$\frac{1}{U(n_1, n_2, n_3, \ldots, n_k)} = w_1 \frac{1}{U_1(n_1)} + w_2 \frac{1}{U_2(n_2)} + w_3 \frac{1}{U_3(n_3)} + \ldots + w_k \frac{1}{U_k(n_k)} = \sum_{i=1}^{k} w_k \frac{1}{U_k(n_k)}, 0 \le U_i(n_i) \le 1,$$

$$\sum_{i=1}^{k} w_i = 1, 0 \le w_i \le 1$$

The amount of weight given to each characteristic in this case relates to its inverses.

The research and prediction of technology changes and futures are becoming increasingly relevant due to the significant and growing importance of technology. While exact forecasts are impossible, technology forecasting offers valuable insights that are much-needed. Technology forecasting fundamental ideas and techniques essentially stay the same. However, the applicability and possibility of the approaches have changed significantly due to the present capabilities for information gathering, communication, and data processing. New techniques that are drawn from the ones that already exist have also emerged. The five categories of technology forecasting techniques are as follows: expert opinion, modeling and simulation, scenarios, trend analysis and statistical approaches, environmental scanning, and road mapping.

Numerous factors can influence farmers' use of technology. Several factors include age, gender, credit availability, and level of education [7-9]**.**Thus, factors that affect the field of psychology lead to the adoption of digital agricultural production-related technology. To determine the likelihood of success in promoting particular technologies, it is therefore necessary to identify these dynamics in the farmers' decision-making processes on technology adoption [10].In accordance with both the threshold decision-making theory and the random utility theory [11,12].Adoption of new technology can only occur when there is a net benefit that exceeds zero, which may be stated mathematically as follows:

$$G_{ij} = E[U(AT)] - E[U(NAT)] > 0$$

The gain or utility received from acceptance and non-adoption of the new technologies are denoted by U(A) and U(NAT), respectively.

V.CONCLUSION

We have studied the models of technology spread using a basic case study and brought in real-world situation. Mathematically, it is possible to predict that adoption will rise up to the number m/2 implies, when 50% of the farmers have adopted the technology, after which it will slow down. In all situations of agricultural innovation, the most typical pattern found under generally stable conditions is a "sigmoid" pattern, in which this variable continuously passes through stages that appear to be exponential, then linear, and ultimately asymptotic to some upper limit. The point of inflection is $y(t) = \frac{m}{2}$ while in real life situation it can occur before or after $\frac{m}{2}$. The role of information technology and the media must be promoted in order to support the adoption of modern irrigation methods so that production per unit area always displays a development curve, even if there isn't enough rain in certain years. Thus, In this investigation, we discover three findings as farmer's adoption behavior, production growth comparision and prediction for upcoming years. Utility function has been used to choose between adopting various technologies.

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