American Journal of Plant Biology
2024, Vol. 9, No. 4, pp. 106-114
https://doi.org/10.11648/j.ajpb.20240904.12

Research Article

Influence of Planting Date on Potato Yield in Gircha Highland, Arba Minch, Ethiopia

Elias Fiseha Mekonnen*

Meteorological Research, Education and Training Lead Executive Office, Ethiopian Meteorology Institute, Addis Ababa, Ethiopia

Abstract

Potatoes are the world's fourth most important food crop, with climate, variety, seed quality, planting timing, nutrition, irrigation, pests, illnesses, and weeds all influencing its growth and productivity. Planting timing is critical for maximizing yields since it regulates temperature and light. Planting date effects on potato development and yield were investigated in an experiment at Gircha Farmland, Arba Minch, from February 8, 2020 to August 19, 2020. The impact of planting dates on potato production response was investigated using the Decision Support System for Agro-technology Transfer (DSSAT) model software application program. The experiment used Gudene cultivar potato root crops in Gircha highland plot areas, with gross plot area, rows per plot, length, and spacing. Harvest area was 2.3 m^2, with two rows, and soil depth was 15 cm. No additional irrigation was supplied, and 150 kg/ha N and 80 kg/ha P fertilizer was applied. Eight planting dates—February 8, February 18, February 28, March 9, March 19, March 29, April 8, and April 18—were selected for this investigation. The relationship between observed and simulated potato yield performance, with RMSE (7.256), IOA (0.842), and R^2 (0.962), and validation values (19.658), IOA (0.827), and R^2 (0.974), indicating good agreement. The latest planting date of April 18 marked the pinnacle of potato output. Furthermore, on April 18, 2020, the planting date that was closest to March 30, 2020, the maximum tuber fresh weight of 48.73 mg/ha was recorded, while on February 8, 2020, the minimum tuber fresh weight of 16.08 mg/ha was acquired. Similar to this, the planting date of April 18^{th} yielded the maximum potato production (9746 kg/ha), while February 8^{th} yielded the lowest yield (3215 kg/ha). Gircha's higher rainfall, lowest solar radiation, and warmer temperatures may have contributed to the crop's increased production. Potato planting date significantly affects growth and yield, with April 18, 2020 being the best date for highest yield. Delays in planting led to increased crop growth and production, influenced by rainfall, solar radiation, and mean temperature.

Keywords

Planting Date, Weather Influence, DSSAT model, Yield of Potato

1. Introduction

Background

Potatoes (Solanum tuberosum L.) are the fourth most important food crop in the world in terms of productivity, behind rice, wheat, and maize [1]. The crop potato is weather-sensitive. Climate, along with a number of other factors such as the adoption of better varieties, high-quality seed,

*Corresponding author: eliasfiseha@gmail.com (Elias Fiseha Mekonnen)

Received: 25 September 2024; **Accepted:** 18 October 2024; **Published:** 28 November 2024

planting timing, nutrition and irrigation, and the prevalence of pests, diseases, and weeds, all affect the plant's development and productivity. One of these factors that is essential to potato output is planting time since it gives you some control over temperature and light. For the maximum yields, the potato crop requires long days for growth and short days for tuberization [2]. Temperature at night and duration of the day are the primary climate variables influencing tuber development [3].

The potato (Solanum tuberosum L.), one of the principal staple crops in the Eastern and Central Africa (ECA) sub-region, is becoming more and more important due to increased urbanisation and consumer demand for processed potato products like crisps and French fries (chips). Sub-Saharan Africa's demand for potatoes is predicted to increase by 250% between 1993 and 2020, with annual demand growth of 3.1% and annual area under production growth of 1.25% [4].

A German immigrant named Wilhelm Schimper brought the potato to Ethiopia in 1858 [5]. Four regions in Ethiopia are the main locations for potato farming: the Central, Eastern, North-Western, and Southern regions. These regions collectively produce over 83% of all potatoes produced in Ethiopia [6]. Potato cultivation in the Central region also includes the highland areas surrounding Addis Ababa, the country's capital. West and North Shewa are the two primary potato-growing regions in this area. Ten percent of potato producers are located in this area [7]. The meher (long rain season, June to October) and belt (short rain season, February to May) seasons are when most potatoes are produced in the central region. Potatoes are also grown under irrigation from October to January during the off-season [7].

With a small portion in the Oromia region, in the southern part of Ethiopia where potatoes are grown, the Southern Nations, Nationalities Potato Production System (SNNPRs) includes all processes and activities (land preparation through harvesting) undertaken to produce ware or seed potatoes and People's Regional States (SNNPRs). The main potato-producing zones in this area include the West Arsi zone in Oromiya and the SNNPRS's Gurage, Gamo Goffa, Hadiya, Wolyta, Kambata, Siltie, and Sidama. Over thirty percent of potato farmers worldwide operate in this region. Growers of potato tubers use both rain- and irrigation-fed systems. Potato productivity can occasionally drop to as low as 7 Mg ha^{-1}, as opposed to the usual range of 7 to 8 Mg ha^{-1} [8].

The main goal of this study was to create a model that suggested when to plant potatoes in Gircha in order to increase productivity.

2. Data and Methodology

2.1. Data

The majority of meteorological and yield data collected from the Gircha Highland Fruits and Vegetables Research Center /GHFVRC/ that was gathered during the experiment time. The crop yield data utilized for DSSAT model calibration and validation. Meteorological data were used impact analysis for this investigation, meteorological weather data from 1/1/2017 to 12/31/22. This data included daily minimum and maximum temperatures as well as rainfall, radiation, and evapotranspiration.

2.2. Methods

2.2.1. Model Description

Researchers from all across the world have been utilizing the decision support system for agro-technology transfer (DSSAT) for the past years. This package combines software with 16 different crop models to make it easier to evaluate and use the crop models for various tasks. The DSSAT crop models have become harder to maintain over the past few years, in part because there were many sets of computer code for various crops with little focus on software design at the level of crop models themselves [9].

Crop simulation models are the core of the DSSAT, a group of independent algorithms that work together. For the sake of adapting the models to various circumstances, databases provide information on the weather, soil, experiment conditions, measurements, and genotypes. Users can construct these databases with the use of software, compare simulated outcomes with observations, and decide whether to make changes to the models to increase accuracy or gain trust in them [10]. At either a plot-field or regional scale, this model can mimic crop growth, development, and yield [11].

2.2.2. Sensitivity Experiment

Sensitivity analysis (SA) can pinpoint the variables that have the greatest impact on crop growth model output, enhancing the effectiveness of model calibration [11].

It is crucial to comprehend how the model responds to a single input, such as meteorological data, cultivars or hybrids, soil data, or values for particular GSPs, in addition to assessing the model with real-world data. Sensitivity analysis is the term used to describe this method, in which all inputs are held constant except one input or parameter. The user can assess the model's sensitivity to changes in cultivars, single GSPs, soil profiles, weather inputs for multiple locations or years, plant and row spacing, and several other parameters using the sensitivity analysis freshly developed tool that is now available in DSSAT [12]. The initial value, the increment value, and the number of iterations can all be changed for variables that have numerical values, such as the planting date [11].

2.2.3. Model Evaluation

Statistical analyses are performed to assess the effectiveness of the DSSAT model. To statistically assess the model's correctness, three statistical indicators the correlation coefficient (CC), index of agreement (IOA), and root mean square error (RMSE) are primarily used. The correlation coefficient (CC) indicates how closely the model and the observed values are related linearly. The Index of Agreement (IOA) measures the degree to which the model accurately captures the pattern of perturbation around a mean value. The root mean square error (RMSE), on the other hand, encapsulates how closely the projected values match the measured values.

Agri-met software.com calculator is used to compute CC, IOA, and RMSE. These are important to check the performance of the model.

$$C(r) = \frac{\sum_{i=1}^{n}(Si-\bar{S})(Oi-\bar{O})}{\sqrt{\sum_{i=1}^{n}(Si-\bar{S})^2 . \sum_{i=1}^{n}(Oi-\bar{O})^2}} \quad (1)$$

$$\text{IOA}=1-\frac{\sum_{i=1}^{n}(Oi-Si)^2}{\sum_{i=1}^{n}|Si-\bar{O}||Si-\bar{O}|^2}, \; 0\leq \text{IOA} \leq 1 \quad (2)$$

$$\text{RMSE}= \sqrt{\sum_{i=1}^{n}\frac{(Si-Oi)^2)}{n}} \quad (3)$$

Where:-

Σ is a fancy symbol that means “sum”

S_i is the simulated value for the i^{th} observation in the dataset

O_i is the observed value for the i^{th} observation in the dataset

$\bar{S}$ Represents the average of the simulated value

$\bar{O}$ Represents the average of observed values

IOA is an index of agreement

CC is Coefficient of correlation

RMSE is Root Mean Square Error

n is the sample size

3. Results and Discussion

3.1. DSSAT Model Description

The data used for model calibration covers the dates 2/8/2020 to 6/10/2020, 2/23/2020 to 6/18/2020, and 3/6/2020 to 6/27/2020, from the planting date to the harvest date. The data used for validation were 3/21/2020 to 7/6/2020, 3/22/2020 to 6/7/2020, and 3/22/2020 to 6/29/2017, which corresponded to the dates of planting and harvesting.

Table 1. *The observed and simulated values of potato yield for model calibration.*

Field treatments	Observed	Simulated	Harvesting date	Planting date		
Gir_02-02-20	29.56	39.4	6/10/2020	2/8/2020	PD1	
Gir_23-02-20	33.05	39.11	6/18/2020	2/23/2020	PD2	Calibration
Gir_06-03-20	14.99	19.93	6/27/2020	3/6/2020	PD3	
Gir_21-03-20	11.09	27.66	7/6/2020	3/21/2020	PD1	
Gir_22-03-22	15.31	35.98	6/7/2020	3/22/2020	PD2	Validation
Gir_07-03-17	23.5	44.89	6/29/2017	3/7/2017	PD3	

3.2. DSSAT Model Performance

The table lists the results of the observed and simulated values of the potato yield performances as RMSE (7.256), IOA (0.842), and R^2 (0.962). The relationship between the observed and simulated validation values were RMSE (19.658), IOA (0.827), and R^2 (0.974).

Good agreement between simulated and observed potato yield were obtained with R^2 of 0.96 and 0.97 under different planting dates for calibration and validation years, respectively. The index of agreement between observed and simulated were good on both the calibration and validation period. The statistical performance values of observed and simulated model results are presented in Table 1.

Table 2. *The result of the observed and simulated values of potato yield for model validation.*

Statistical Indicators Value	RMSE	IOA	R^2
Calibration	7.256	0.842	0.962
Validation	19.658	0.827	0.974

3.3. General Information of Experiment

In Gircha highland experimental plot areas, potato root crops of the Gudene cultivar were used for the experiment. The gross plot area per representative (5.2 m^2), rows per plot

(4 m), plot length (1.8 m), and plot spacing (1.8 cm) were the plot details for the experiment. The following data are also being collected for the experiment: Harvest area is 2.3 m^2; there are two harvest rows, and each row is 1.8 m in length.

The depth of the soil (base of the layer) during the experiment was taken 15 cm and no further irrigation water was used for the crop. It exclusively makes use of water from rainfall. Throughout the experiment, 150 kg/ha N and 80 kg/ha P of fertilizer were applied.

3.4. Effect of Different Planting Dates on Yield Parameters of Potato

At the Gircha Farmland between February 8, 2020 (the start of planting date), and July 20, 2020 (the completion of the experiment), a DSSAT model experiment was carried out to evaluate the impact of planting dates on the growth and yield response of potatoes up the end of the last harvesting date. For this study, eight planting dates (PDs) were chosen: February 8 (PD1), February 18 (PD2), February 28 (PD3), March 09 (PD4), March 19 (PD5), March 29 (PD6), April 08 (PD7), and April 18 (PD8), with a row spacing of 70 cm and 4.7 plants per square meter. The planting dates were gaped 10 days apart.

The model could simulate potato yield more accurately from the second planting date to the final planting date on this experiment for the simulation of potato yield under various planting dates.

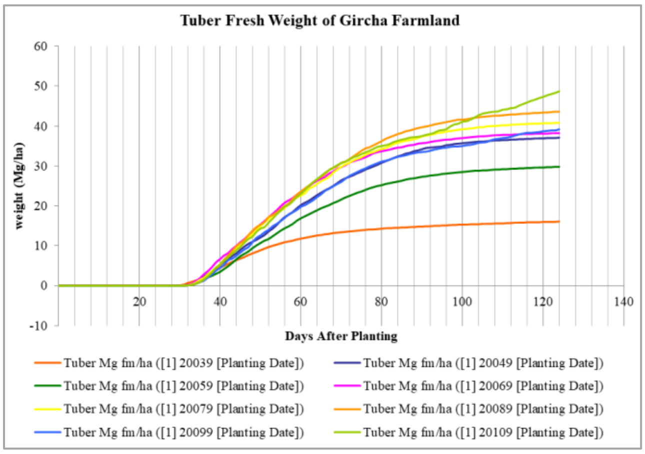

Figure 1*. Tuber fresh weight (Mg/ha) harvest in different planting dates.*

Table 3*. Effect of different planting dates on yield parameters of potato.*

Planting dates		Harvesting dates	Tuber fresh weight (Mg /ha) harvest	Potato Yield (Kg/ha)
PD1	02/08/2020	06/10/2020	16.08	3215
PD2	02/18/2020	06/20/2020	37.07	7414
PD3	02/28/2020	06/30/2020	29.80	5960
PD4	03/09/2020	07/10/2020	38.21	7643
PD5	03/19/2020	07/20/2020	40.83	8167
PD6	03/29/2020	07/30/2020	43.63	8726
PD7	04/08/2020	08/09/2020	39.19	7837
PD8	04/18/2020	08/19/2020	48.73	9746

3.5. Tuber Fresh Weight Harvest

Amongst the various planting dates, there were significant differences in tuber fresh weight (Mg /ha) harvest ranging from 16.08 to 48.73. The lowest tuber fresh weight (16.08 Mg/ha) and the highest tuber fresh weight (48.73 Mg/ha) were recorded on planting dates PD1 and PD8, respectively. This finding leads us to the conclusion that the PD8 has a higher potential for higher tuber fresh weight than other dates.

3.6. Potato Yield

The number of tubers produced per hectare varied significantly among the eight planting dates that were being studied. The highest yields of 9746 kg per hectare, 8726 kg per hectare, 8167 kg per hectare, 7837 kg per hectare, 7643 kg per hectare, and 7414 kg per hectare, respectively, were observed on the planting dates of PD8, PD6, PD5, PD7, PD4, and PD2. The planting date of PD1 (3215 kg/ha) and PD3 (5960 kg/ha) were produced the lowest yields.

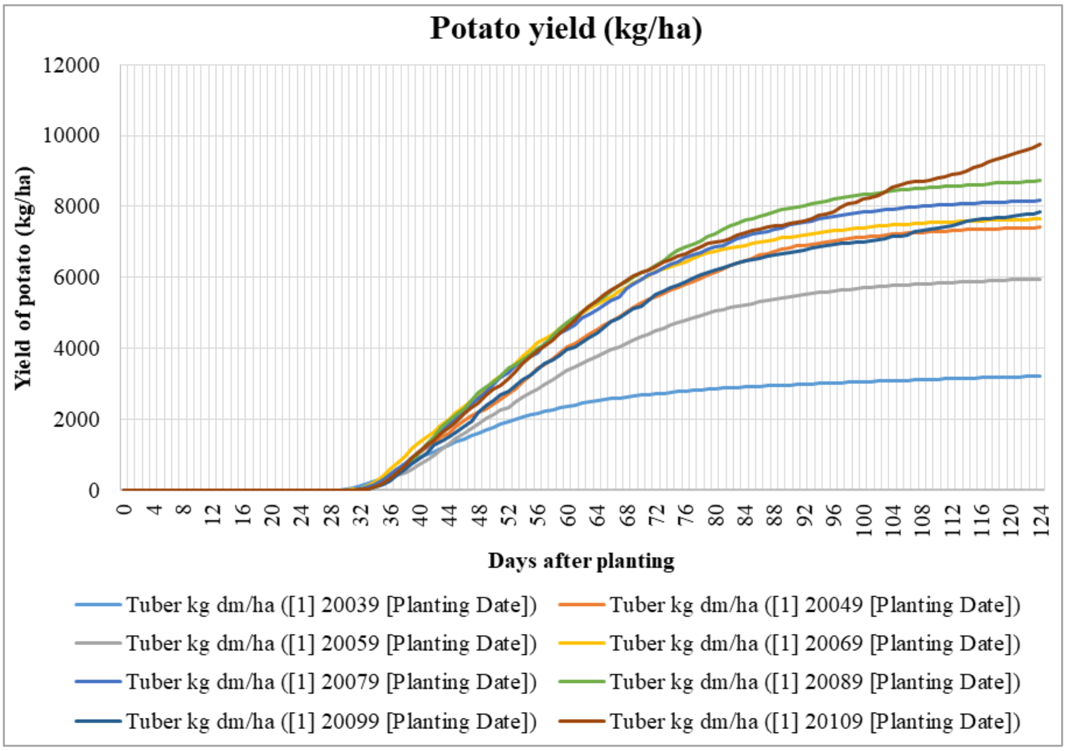

Figure 2. *Yield of potatoes on different planting dates.*

3.7. Weather Conditions and Growth and Development Variables

Environmental conditions in general and temperature in particular, have a considerable impact on potato yield. Crop characteristics like plant height, leaf count, number of tubers, and tuber weight are key contributors to yield [2]. The robust vegetative growth in terms of height and the number of leaves, as well as the stronger reproductive growth in terms of the greater quantity and weight of tubers at the time of planting on PD8, may have favored a higher yield at this planting date.

The values of rainfall from planting to harvesting date on the last experiment were higher and the solar radiations were lower than the other seven experiments might have been important to better vegetative growth and a maximum yield of potatoes on this planting date.

Apart from increased precipitation and reduced solar radiation, temperature is the primary determinant of potato yield. Lower mean temperatures required from planting to harvesting may have reduced evaporation from the farmland's surface and prolonged the retention of moisture in the soil layer. This may have been crucial for improved vegetative development and a greater yield at this planting date.

With various planting dates and potato yields, the key average meteorological conditions from potato planting to harvesting date are presented in table 4. The main growth and development variables and Summary of soil and genetic input parameters are presented in Table 5 and *Table 6*. The yield parameters of root weight, leaf weight, steam weight, and leaf area index are tabulated in *Figure 3*, *Figure 4*, *Figure 5*, and *Figure 6*.

Table 4. *Main means weather conditions during the potato growth period on different planting dates.*

Experiments	Mean Temperature ℃	Rain (mm)	Solar Rad. MJ/m^2	Potato Yield (Kg/ha)
PD1	12.9	314.2	16.5	3215
PD2	12.8	302.4	16.0	7414
PD3	12.6	284.0	15.3	5960
PD4	12.5	270.4	14.7	7643
PD5	12.4	286.6	14.3	8167
PG6	12.2	291.0	14.0	8726

Experiments	Mean Temperature ℃	Rain (mm)	Solar Rad. MJ/m^2	Potato Yield (Kg/ha)
PG7	12.0	299.1	12.9	7837
PG8	11.8	320.4	12.4	9746

Table 5. *Main growth and development variables.*

Variable/Planting date	PD1	PD2	PD3	PD4	PD5	PD6	PD7	PD8
Tuber initiation day (dap)	29	31	31	31	31	32	32	32
Tuber dry weight (kg /ha) harvest	3215	7414	5960	7643	8167	8726	7837	9746
Tuber fresh weight (Mg /ha) harvest	16.08	37.07	29.8	38.21	40.83	43.63	39.19	48.73
Total weight, harvest (kg /ha)	3571	8011	6506	8304	8901	9476	8587	10773
By-product produced (stalk) at maturity (kg/ha)	16782	37653	30578	39029	41837	44538	40357	50635
Leaf area index, maximum	1.03	1.61	1.33	2.09	2.34	2.17	1.86	2.55
Tuber N at harvest (kg/ha)	48.38	98.86	85.86	98.8	114.44	117.41	111.15	139.77
Tuber+stem+leaf N at harvest (kg/ha)	24.99	12.07	18.7	12.75	25.13	16.57	29.99	39.4
Tops N at maturity (kg/ha)	24.99	12.07	18.7	12.75	25.13	16.57	29.99	39.4
Tuber N at harvest (%)	1.505	1.333	1.44	1.293	1.401	1.346	1.418	1.434
Emergence day (dap)	10	10	10	10	10	10	10	10

Table 6. *Summary of soil and genetic input parameters.*

SOIL DEPTH (cm)	LOWER LIMIT (cm^3/c)	UPPER LIMIT (M^3)	SAT SW (cm^3/cm)	EXTR SW (cm^3/cm^3)	INIT SW (cm^3/cm^3)	ROOT DIST	BULK DENS (g/cm^3)	pH	NO_3 (ugN/g)	NH_4 (ugN/g)	OR-GIC%
0- 5	0.351	0.47	0.485	0.119	0.47	1	1.17	7	0	0	2.9
5-15	0.354	0.473	0.488	0.119	0.473	1	1.21	7	0	0	2.91
15- 28	0.374	0.491	0.506	0.117	0.491	0.75	1.19	7	0	0	2.45
28- 36	0.395	0.51	0.525	0.115	0.51	0.75	1.13	7	0	0	1.48
36- 44	0.395	0.51	0.525	0.115	0.51	0.75	1.13	7	0	0	1.48
44- 54	0.415	0.527	0.542	0.112	0.527	0.5	1.07	7	0	0	0.76
54- 65	0.415	0.527	0.542	0.112	0.527	0.5	1.07	7	0	0	0.76
65- 80	0.427	0.536	0.551	0.109	0.536	0.5	1.08	7	0	0	0.36
80- 96	0.427	0.536	0.551	0.109	0.536	0.5	1.08	7	0	0	0.36
96-122	0.437	0.549	0.564	0.112	0.549	0.25	1.01	7	0	0	0.23
122-150	0.441	0.553	0.568	0.112	0.553	0.25	1	7	0	0	0.15
150-178	0.428	0.541	0.556	0.113	0.541	0.12	0.99	7	0	0	0.14
178-196	0.371	0.488	0.503	0.117	0.488	0.12	1.1	7	0	0	0.08
196-230	0.371	0.488	0.503	0.117	0.488	0.05	1.1	7	0	0	0.08
230-260	0.371	0.488	0.503	0.117	0.488	0.05	1.1	7	0	0	0.08

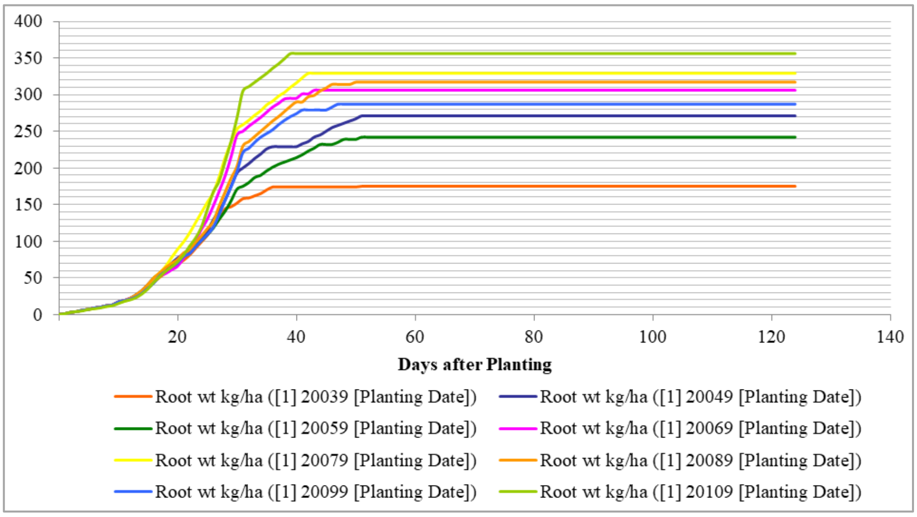

Figure 3. *Root weight (yield parameter).*

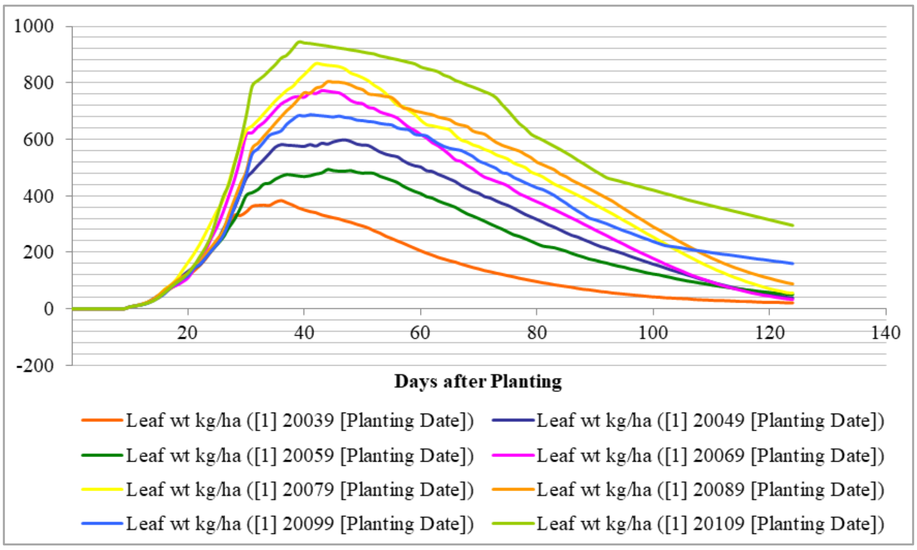

Figure 4. *Leaf Weight (yield Parameter).*

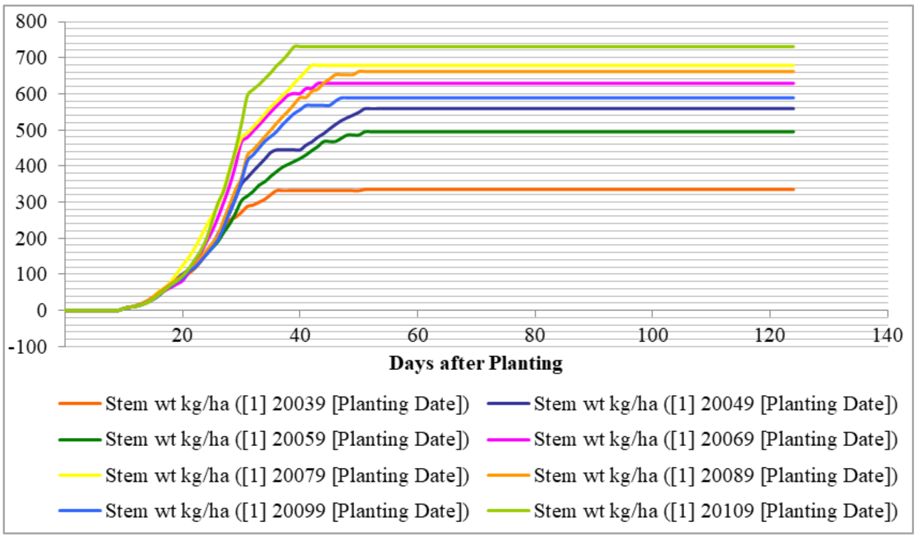

Figure 5. *Steam Weight (yield parameter).*

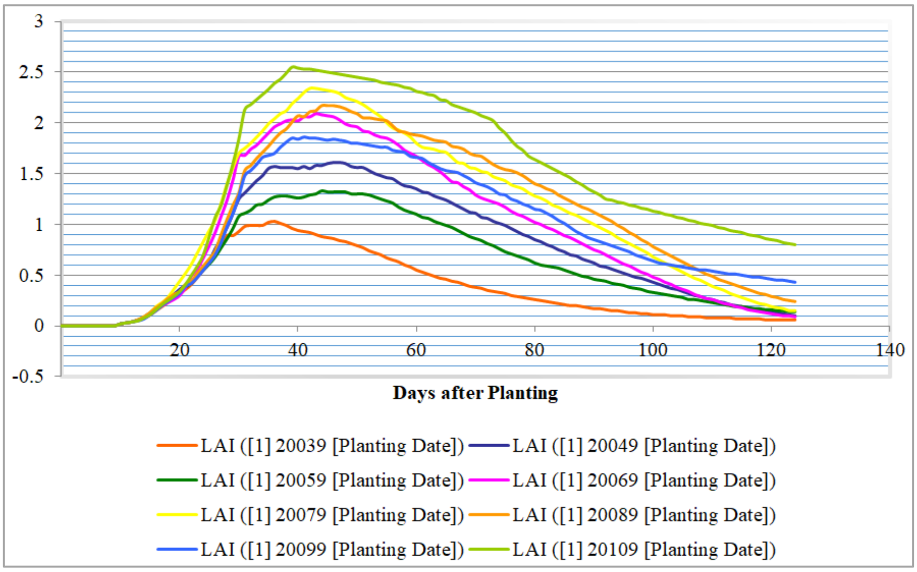

Figure 6*. Leaf Area Index (yield parameter).*

4. Conclusion

Potato planting date was found to have a significant impact on certain growth and yield aspects. Because of the delayed planting, the potato crop in the study region expanded and produced more. The DSSAT model simulation result on the trial field indicated that April 18, 2020, was the best date to plant potatoes in order to achieve the highest yield. Rainfall, sun radiation, and mean temperature together accounted for three meteorological weather characteristics that significantly impacted potato output production.

Abbreviations

DSSAT	Decision Support System for Agro-technology Transfer
GHFVRC	Gircha Highland Fruits and Vegetables Research Center
GSPs	Genotype-specific model Parameters
LAI	Leaf Area Index
PDs	Planting Dates
SNNPRS	Southern Nations Nationalities and Regional State

Acknowledgments

We would like to thank the GHFVRC for providing us with invaluable raw data.

Author Contributions

Elias Fiseha Mekonnen is the sole author. The author read and approved the final manuscript.

Funding

For the study they presented, the authors received no support from any organization.

Data Availability Statement

Meteorological and yield data for this study were obtained from GHFVRC.

Conflicts of Interest

The author declares no conflicts of interest.

References

[1] N. Singh, A. Singh, and K. Singh, “Effect of Time of Planting on Growth and Yield Parameters of Potato Crop,” Int. J. Curr. Microbiol. Appl. Sci., vol. 9, no. 5, pp. 2847–2851, 2020, https://doi.org/10.20546/ijcmas.2020.905.326

[2] B. Thongam et al., “Influence of planting dates on growth and yield of potato (Solanum tuberosum L.),” J. Pharmacogn. Phytochem., vol. 6, no. 6, pp. 1243–1246, 2017, [Online]. Available: http://www.phytojournal.com/archives/2017/vol6issue6/PartR/6-6-37-819.pdf

[3] C. Press, “The Role of Daylength and Temperature in Tuber Formation and Rhizome Growth of Trientalis borealis Raf. Author (s): Roger C. Anderson Published by : The University of Chicago Press Stable URL : https://www.jstor.org/stable/2473949 The University of Ch,” vol. 131, no. 2, pp. 122–128, 1970.

[4] C. J. W. Carroll et al., "Is a drought a drought in grasslands? Productivity responses to different types of drought," Oecologia, vol. 197, no. 4, pp. 1017–1026, 2021, https://doi.org/10.1007/s00442-020-04793-8

[5] B. Haile, A. Mohammed, and G. Woldegiorgis, "Effect of Planting Date on Growth and Tuber Yield of Potato (Solanum tuberosum L.) Varieties at Anderacha District, Southwestern Ethiopia," Int. J. Res. Agric. Sci., vol. 2, no. 6, pp. 272–280, 2015.

[6] A. N. Wassihun, T. D. Koye, and A. D. Koye, "Analysis of technical efficiency of potato (Solanum tuberosum L.) production in Chilga District, Amhara National Regional State, Ethiopia," J. Econ. Struct., vol. 8, no. 1, 2019, https://doi.org/10.1186/s40008-019-0166-y

[7] D. Milkias, "Potato Production and Marketing by Small Holder Farmers in Ethiopia: A Review Study," J. Nat. Sci. Res., vol. 12, no. 16, pp. 9–15, 2021, https://doi.org/10.7176/jnsr/12-16-02

[8] Helen, "A review on potato (Solanum tuberosum L.) production situations in Ethiopia," Food Sci. Qual. Manag., vol. 57, pp. 32–35, 2016.

[9] J. W. Jones et al., The DSSAT cropping system model, vol. 18, no. 3–4. 2003. https://doi.org/10.1016/S1161-0301(02)00107-7

[10] K. C. Dejonge and K. R. Thorp, "Dssat c," vol. 60, no. 56, pp. 1965–1981, 2017.

[11] G. Hoogenboom et al., "The DSSAT crop modeling ecosystem," pp. 173–216, 2019, https://doi.org/10.19103/as.2019.0061.10

[12] R. S. Singh, K. K. Singh, and G. B. Gohain, "Simulating crop yield using the DSSAT v4.7-CROPGRO-soyabean model with gridded weather and soil data," Model. Earth Syst. Environ., vol. 10, no. 1, pp. 845–853, 2024, https://doi.org/10.1007/s40808-023-01807-1