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Research Article

Onset of Rainfall and Cumulative Analysis for Sorghum Cultivation in Baringo County

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Abstract

Sorghum is an essential food security crop in the majority of the ASALs regions, such as Baringo County. This study investigated the critical relationship between rainfall levels and the initiation of sorghum planting, with the aim of identifying the threshold at which rainfall is considered sufficient for germination and optimal growth. This study used historical meteorological data from 1990 to 2022, field experiments, statistical analysis, and sorghum growth patterns to discern the trigger points for planting, which are essential for ensuring successful cultivation. This study uncovered alterations in rainfall onset and seasonal rainfall accumulation. The planting window in Baringo County varied significantly, with some dates falling above and below the average onset values of April 4th for the long rainfall season and September 24th for the short rainfall season. A short rainy season is not ideal for sorghum planting, as it typically receives less than 300 mm of rainfall, which is insufficient for sorghum production. The optimal planting time for sorghum is usually late March and early April. The study found that 36.4% of the long rainy season years had high production, 42.4% had normal production, and only 21% had low or no productivity. The years 2000 and 2018 experienced minimum and maximum rainfall amounts of 198.45 mm and 941.9 mm, respectively.

Keywords

Sorghum, Rainfall Onset, Planting Window, Trigger Point, Food Security

1. Introduction

Climatic data provides valuable information regarding the suitability of the environment for crop growth and development. In particular, the timing and amount of rainfall are crucial factors in determining planting dates [1]. The onset of the rainy season plays a significant role in agricultural management, as it ensures sufficient soil moisture during planting and early growing periods, reducing the risk of crop failure. Water use for most crops is affected by two critical factors: growth stage and environmental demands [2]. Environmental demands mainly include rainfall, humidity and daily temperatures. Areas with high humidity demand less water than those with low humidity. Similarly, areas with high temperatures also demand more water than those with relatively low temperatures. However, there are differences in the use of water because of the varying growth and maturity of various crops. Most ASALs regions such as Baringo County regularly experience water stress. These regions are classified as Arid and Semi-Arid Lands (ASALs), owing to their ability to receive low amounts of rainfall. Some of the effects of water stress include a reduction in cell expansion rate, cell size, stem

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elongation, growth rate, and leaf expansion which results in the death of the crop [2]. Therefore, farmers must know the sufficient amount of water they need before planting their seeds and determine the most suitable planting date for their region by understanding the climatic conditions and using appropriate techniques. Rainfall during the planting period is crucial for sorghum because it determines the germination, root establishment, and early growth of the crop [3]. Insufficient rainfall during this period can lead to poor germination, stunted growth, reduced tillering, and an overall yield potential. Determining the optimal moisture amount for sorghum during the planting period is crucial for ensuring healthy growth, maximum yield potential, and mitigating the risks associated with both water stress and excess moisture. Sorghum plants that receive optimal rainfall during the planting period are more likely to have a higher yield potential than those that experience water stress or excess moisture.

The traditional sowing strategy employed by farmers in Marigat is dry and wet. Dry seeding entails planting before the rainy season, when the soil is still dry, whereas wet seeding involves planting after rainfall. However, both methods present certain challenges, such as high soil temperatures or irregular rainfall, which can negatively affect seed germination and early development of the crop. Additionally, sowing after rainfall may result in the seed receiving sufficient moisture to begin germination but insufficient moisture for the seed to sustain early growth, ultimately leading to wilting of the crop.

The accurate prediction of the onset and duration of the growing season has crucial implications for smallholder farmers [31]. This prediction allows farmers to synchronise their planting activities with the beginning of the growing season, optimise soil moisture utilisation, and mitigate the risks of crop failure from untimely planting. Anticipating the timing of the growing season empowers farmers in effective water resource planning, particularly in rain-fed agricultural systems. Furthermore, these accurate predictions serve as valuable tools for farmers to proactively manage climate-related risks, adapt agricultural practices, and bolster food security by improving crop production and reducing vulnerability to climate-induced shocks. The insights also guide decision-making on various agricultural practices, such as land preparation, fertiliser application, and pest management, fostering more efficient and sustainable farming practices [11].

Climatic factors, such as rainfall amount, distribution, and onset/cessation of rain, have a direct impact on crop yields and determine the agricultural calendar. Critical stages such as germination require enough rainfall; however, insufficient moisture results in stunted growth, reduced grain formation, and low yield. On the other hand, excessive rainfall during the planting season affects seeds, leading to rot and damage, which results in low sorghum production [4]. Germination is an essential stage in crop development, and sufficient water is required for the establishment of healthy crops [5].

The primary trigger for various farmers to start planting sorghum in ASAL areas is the perceived reliability and availability of moisture during the planned planting date and for the growing season [3]. Moisture is specifically tied to the advent of the rainy season. Therefore, after land preparation, farmers are ready to start planting as soon as there is perceived availability of rains. Hence, rain plays a critical role in the planting of most crops in ASALs as well as in other regions globally. Before embarking on planting, a number of factors must be observed by farmers to provide them with a green light on when to start planting. The pattern of rain is an essential factor because early rain may disappear immediately after planting. In the event of rain disappearance, farmers may lose their investments [6]. It is necessary to wait for the first rain to accumulate to a threshold level in order to provide green light for planting. The reason for this accumulation is to build enough moisture necessary for kick-start germination as well as to facilitate the initial growth stages. Because irrigation is rarely practiced in Baringo County for sorghum cultivation, waiting for sufficient moisture buildup is critical to ensure crop maturity.

Historically, farmers in Baringo have relied on the onset of rainfall to know when to plant which has really worked to their disadvantage in terms of resource input. Adequate rainfall during the planting period ensures sufficient soil moisture for seed germination and early growth, leading to better crop establishment. This in turn promotes root development, nutrient uptake, and overall plant growth. Farmers need to consider the specific requirements of sorghum at each stage of its growth and aim for a rainfall amount that provides sufficient moisture without being in excess.

This calls for scientific knowledge useful for predicting the changing climatic conditions that affect seed germination. For successful crop production, it is prudent to understand the optimal amount of rainfall that is essential for germination before placing seeds in the soil. However, the required amount of rainfall depends on several factors, such as soil type, crop variety, and local climate [7]. For the ASALs regions, it is necessary to understand the required amount of rainfall to avoid losses from crop production.

Sorghum crop

Sorghum, commonly known as *Sorghum bicolor*, is a cereal crop ranked as the fifth most vital cereal grain in the world after wheat, maize, rice, and barley [10]. Its cultivation is common in developing countries, with Asia and Africa being its largest producers. Globally, Africa produces approximately one-third of sorghum. Cereal dominance in Africa is attributed to its adaptability and suitability for tropical conditions experienced in Africa [11]. Sorghum is an essential crop for most households in sub-Saharan Africa. Therefore, ensuring food security in Africa and Asia is vital [12]. The crop can perform well under unfavourable, favourable, and harsh weather conditions that are prevalent in the majority of ASAL regions [9]. This is because the crop can withstand prolonged periods of drought and high temperatures, which characterise these ASAL regions. In addition, crops can endure prolonged periods of waterlogging. As a result of increasing global warming as well as climate change, sorghum seems to be a promising alternative for both enhanced income as well as food security as compared to other cereals such as maize, which are prone to failures due to harsh weather conditions [13].

Sorghum production potential in Kenya ranges from 2 to 5 ton/ha against the realized production yield of 0.7 tons/ha which is unlikely to meet the ever-increasing domestic market [10]. In Kenya, sorghum production is practiced in both marginal and semi-arid regions that experience high temperatures and low and erratic rain. Low amounts of rainfall and high temperatures cause these regions to experience challenging agricultural conditions. In Kenya, ASALs regions include parts of eastern, northeastern, coastal, Rift Valley, and Nyanza Province. These areas have remained the largest producers of sorghum in the country. For example, in 2014, close to 1.9 million bags (90 kg) of sorghum were produced, and both the Eastern and Nyanza provinces recorded the highest volume of production. The provinces produced 761,414 and 757,862 bags, respectively [12].

Sorghum crops have excellent water extraction techniques for soil. This ability enables it to survive in harsh areas where other cereals such as maize cannot survive. Approximately 90% of the total water used by sorghum crops is extracted from soil. Soil depth should range from 0 to 1.65 m. Sorghum crop remains a good choice for commercial subsistence farming [12]. This is because the crop has diverse uses, ranging from food and breweries (alcohol production) to biofuels and livestock feed (fodder). However, the success of sorghum production relies heavily on the knowledge of rainfall patterns and essential crop growth requirements. Sufficient rainfall is required for crop maturity; therefore, this study examined the rainfall patterns within Marigat, Baringo County, to determine the rainfall needed at the time of planting.

As noted by Carcedo et al., (2021), early planting is vital for this crop and soil temperature plays a major role in the germination rate. This crop requires warmer soil temperatures greater than 18 ℃ for rapid and dependable emergence. This temperature can be easily attained in ASALs regions. At the target planting depth, this temperature should be measured and recorded early in the morning to assess the germination conditions. To characterise planting suitability, the daily low temperature should be measured and recorded. Throughout the year, the climate in Baringo County is warm, with temperatures typically ranging between 18 ℃ and 32 ℃ [14]. Understanding compensatory effects in sorghum genotypes under different water regimes helps in overcoming the water stress triggered after drought [10]. To avoid water stress, the crop requires approximately 1–2.5 mm of water per day [2].

Criteria used to determine the first planting dates

The start of the growing season is the date when accumulated rainfall exceeds one half of the potential evapotranspiration for the remainder of the growing season, so long as there is no dry spell longer than five days immediately after this date [15]. The start of the growing season is the 10-day in which rainfall is equal to or greater than 25 mm, but where the successive 10-day rainfall total is more than half of the potential evapotranspiration [16].

Several techniques exist to determine the onset and cessation dates of rainfall in Kenya. They are grouped into traditional techniques, accumulated rainfall totals, and rainfall–evapotranspiration relationships. These techniques include Walter’s method (fraction of evapotranspiration), hierarchical Bayesian model, percentage cumulative mean model, ogive method, inter-tropical discontinuity rainfall model, and the rainfall evapotranspiration model [17]. Unlike other methods that rely on indirect factors, such as evaporation, humidity, and atmospheric pressure, Walter's method utilises rainfall data that are readily available and directly measured [17]. Walter's method outshines others in terms of both accuracy and ease of implementation.

Gudoshava et al. (2020b) method utilises the number of rainy days and spell lengths. A wet day is characterised by an accumulated rainfall of at least 1 mm. The onset of the wet season is determined by the first day when a prolonged period of rainfall, lasting for at least three consecutive days, amounts to at least 20 mm, and there is no dry spell of at least seven days within the following 20 days [18, 29].

The most commonly used methods in the literature are those that apply threshold values to the total rainfall amount [19, 20]. According to Marteau et al. (2011), the onset of a 3-day period of continuous precipitation amounts to at least 20 mm, without any break in precipitation for 10 consecutive days, within the next 20 days.

Some criteria applied in Zimbabwe to determine the first planting dates for farmers are the AREX criterion developed by the Ministry of Land and Agriculture, the MET criterion developed by the Ministry of Transport and Energy, and the DEPTH criterion developed in a study by Raes et al. (2004) as an alternative. The AREX criterion is based on the requirement of 25 mm rainfall in seven days, and the MET criterion requires 40 mm rainfall in 15 days. The DEPTH method involves farmers inspecting the soil conditions for planting by digging a test hole after a rain event to form a recognisable wetting front. This method quantifies the cumulative rainfall depth over a maximum of four days, with the aim of bringing the top 0.25m of the soil profile to field capacity. A cumulative total of 40 mm of rainfall received during a maximum of four successive days is proposed as a practical guideline for farmers using the DEPTH method, which is applicable to all soil types, as the required rainfall does not vary significantly across different soil types. These criteria were used to advise farmers on when to plant at the onset of the rainy season. [21].

Table 1. *Rainfall amount required to wet the top 0.25m of an initially dry soil profile (at wilting point).*

Soil type	TAW (total available soil water) (mm/m soil depth)	Required rainfall (mm)	Rainfall + 20% (mm)
Clay	126	32	38
Sandy clay	117	29	35
Sandy clay loam	127	32	38
Sandy loam	138	35	41
Loamy sand	114	29	34
Sand	90	23	27

Source: [21]

A threshold value of 40 mm of rainfall was established by increasing the TAW values by 20%, as shown in Table 1, to account for losses due to surface runoff, uneven wetting, and soil evaporation due to the high temperatures experienced in ASALs areas.

Growing Degree Days (GDD) are a measure used to estimate crop development and yield potential based on temperature data [22]. The calculation of growing degree days is one method that can also be used to determine the first planting date based on climatic data. To calculate the total growing degree days for each planting date, the equation below can be applied [23].

$$GDD = \sum_{i=1}^{n}(T_m - T_b) \quad (1)$$

Where;

T_m: The mean daily temperature (averaged over all readings)

T_b: The base temperature; the temperature below which plant growth is considered to be zero

n: The number of days elapsed

Factors such as the length of the growing season, available water resources, and potential weather fluctuations are considered because they can help determine the best first planting date to maximise crop yield and minimise the risk of crop failure. By analysing the temperature data and calculating the total growing degree days for each potential planting date, farmers and researchers can determine the optimal first planting date that will provide the highest expected yield for the specific crop being planted [24].

The threshold water required by farmers to trigger planting of sorghum is 2.5 mm, which yields a moisture index equivalent to 40 % [2]. A moisture index of 40% in the ASALs region can be achieved by annual rainfall of 450–900 mm. However, these areas rarely experience more than 750 mm of rain annually, except during flooding. The soil moisture level is critical for seed germination. An inadequate soil moisture index may lead to germination failure. Therefore, farmers must wait for the soil to gather sufficient moisture before planting seeds. The threshold of water (2.5 mm) may be sufficient to support germination which may rise to 3.5 mm/day or more due to the event of high temperatures as experienced in ASALs regions. The majority of ASALs regions tend to experience warm temperatures as early as 9AM up to 6 PM. At times, these regions experience extreme temperatures, which escalate evapotranspiration. A large amount of water, in terms of moisture, is lost at high temperatures, leading to soil dryness. However, as the crop advances to the 7-leaf stage, the water requirements drastically increase. The 7-leaf stage occurs within the first 30 days after germination. Sufficient water requirements increase to 7–10 mm/day until the crop reaches the boot stage [2]. Sorghum crops have excellent water extraction techniques for soil. This ability enables it to survive in harsh areas where other cereals such as maize cannot survive. Approximately 90% of the total water used by sorghum crops is extracted from soil. Soil depth should range from 0 to 1.65 m. As indicated in Table 2, the ASALs areas experience a moisture index between 15 and 40%.

Table 2. *Agro-climatic characteristics of ASALs in Kenya.*

Agro-Climatic Zones	Classification	Moisture Index (%)	Annual Rainfall (mm)	Land area (%)
IV	Semi-humid - semi-arid	40-50	600-1100	5
V	Semi-arid	25-40	450-900	15
VI	Arid	15-25	300-550	22

Agro-Climatic Zones	Classification	Moisture Index (%)	Annual Rainfall (mm)	Land area (%)
VII	Very arid	<15	150-350	46

Source. Modified from [25]

2. Materials and Methods

The climate in Kimorok can be described as warm and overcast. The average annual temperature ranges from 18℃ to 33℃. In extreme cases, the temperature can decrease to 16℃ for the lowest value and increase to 34℃ for the highest value.

Weather-related information was analysed over a specific study period, that is, 1990 to 2022. These data included parameters such as temperature, precipitation, humidity, wind speed, and solar radiation. For planting, precipitation and temperature were analysed. By analysing climatic data, farmers can gain insights into prevailing weather patterns and make informed decisions about the best planting date for their crops. Descriptive statistics, such as minimum, maximum, sum, and range, were used to describe the rainfall parameters and temperature.

Mhizha et al., (2014a) & Raes et al., (2004), descriptions in which they defined agricultural rain (wet) day occurs when an area receives 4.95 mm or more of rainfall, 2.95 mm or more of rainfall is a rainy day, any day that accumulates less than 2.95 mm of rain is a dry day and at least 100 mm of rain within five consecutive days is waterlogging [26]. Looking at the geographical location, a rainfall of more than 2.5 mm as a rainy day and less than 2.5 mm as a dry day was adopted in Baringo having applied the Indian Institute of Tropical Meteorology (IMD) that defined 'dry days' as continuous period with daily rainfall equal to or less than daily mean rainfall over the area of interest [27]. The IMD defines a dry day as a day when rainfall is less than 2.5 mm [28].

The onset of rainfall was modified from the definition used by Mupangwa et al., (2011) where onset was defined as the first day after 1 March when the rainfall accumulated over 3 days was at least 20 mm, and to avoid a false start through long dry spells, a condition was set such that the day should not be followed by nine consecutive dry days within 21 days of the start date. The risks of dry spells of 10 days or more in the planting window between 15th March and 15th April were determined.

Statistical analysis

The R statistical system was employed in this study to determine the optimised onset of rainfall that could initiate planting and enable plants to grow to maturity.

Precipitation indices used in this study.

Consecutive dry days (CDD), days

Let RR_{ij} be the daily precipitation amount on day i in period j. If N represents the number of days in *j*, count the largest number of consecutive days where $RR_{ij} < 1mm\ and\ Total\ wet - day\ precipitation, mm$

$$TOTPCP_j = \sum_{n-1}^{N} RR_j \quad (2)$$

Very wet-day precipitation, mm

Let R_{wj} be the daily precipitation amount on a wet day w (RR ≥ 1.0 mm) in period j and let $R_{wn}95$ be the 95th percentile of precipitation on wet days in the 1990–2022 period. If W represents the number of wet days in the period,

$$then\ R95p_j = \sum_{w-1}^{W} R_{wj},\ R_{wj} > R_{wn}95 \quad (3)$$

If W represents number of wet days in j,

$$then\ simple\ daily\ intensity\ index, \frac{mm}{day}$$

$$SDII_j = \left(\sum_{n-1}^{N} RR_j\right) \Big/ W \quad (4)$$

This is based on mathematical principles that describe the random variation of a set of observations

$$\bar{X} = \frac{1}{n}\sum_{n-1}^{n} x_1 \quad (5)$$

$$s^2 = \frac{1}{n-1}\sum_{n-1}^{n}(x_i - \bar{X})^2 \quad (6)$$

$$s = \left(\frac{1}{n-1}\sum_{i-1}^{n}(x_i - \bar{X})^2\right)^{1/2} \quad (7)$$

$$CV = \frac{s}{\bar{x}} \times 100 \quad (8)$$

Where;

$\bar{X}$: The sample mean

n: The number of observations

x_1: The individual observation for i= 1, 2, 3...n

s^2: The Variance

s: The standard deviation

CV: The coefficient of variation

According to Hare (2003), CV is used to classify the degree of variability of rainfall events as less if CV < 20, moderate if 20 < CV < 30, and high if CV > 30.

Farmers can use rainfall data to estimate the soil moisture availability during different planting periods. Once all the relevant data and variables were considered, the information was used to determine the first planting date that would optimise crop emergence and yield.

3. Results and Discussion

To determine the optimal rainfall for sorghum during the planting period, it is necessary to consider several factors, such as soil type, crop growth stage, local weather patterns, historical rainfall data, conducting field experiments, and statistical analysis which can provide insights into the typical soil moisture levels during the planting period. These factors play a significant role in the water requirements of sorghum during its early growth stages. This allows farmers to make informed decisions regarding supplemental water requirements by optimising water usage, minimising costs, and reducing the risk of over- or under-watering their sorghum crops. It also helps farmers to assess the risk of waterlogging or excessive moisture in their fields which allows them to implement proper drainage systems or select well-drained areas for planting, mitigating the risk of waterlogged soil, which can hinder soil aeration, root development, and lead to disease. By doing so, they can better predict and manage potential drought conditions, adjust their planting schedule if necessary, or implement irrigation strategies to ensure that the crop receives adequate moisture at a critical early growth stage.

Table 3. Summation of the rains at different intensity during the long season.

Year	Sum of rainfall	Sum of rain 20mm	Sum of rain 10mm	Sum of rain 5mm	Sum of rain 2.5mm	Sum of rain 1mm	Start of rain (doy)	Start of rain (date)
1990	343.35	1	9	23	42	79	92	01/04/1990
1991	323.99	0	2	22	46	79		
1992	291.81	0	2	22	43	72	99	08/04/1992
1993	267.68	0	2	13	39	76	125	04/05/1993
1994	518.66	2	17	35	64	96	112	21/04/1994
1995	326.93	0	6	14	46	90	62	02/03/1995
1996	362.83	1	4	25	49	93		
1997	497.18	5	16	36	53	75	95	04/04/1997
1998	429.14	1	8	27	56	100	124	03/05/1998
1999	315.26	1	3	13	44	84		
2000	198.45	0	1	6	36	67		
2001	447.26	1	5	37	72	95	83	23/03/2001
2002	381.96	0	10	23	52	82	63	03/03/2002
2003	574.83	4	12	37	75	100	104	13/04/2003
2004	312.18	2	5	23	43	69	101	10/04/2004
2005	377.36	2	5	23	57	88	118	27/04/2005
2006	256.68	2	3	9	32	83	94	03/04/2006
2007	451.26	1	9	32	62	89	103	12/04/2007
2008	259.38	1	2	7	35	86		
2009	243.22	1	5	10	27	68	132	11/05/2009
2010	523.65	0	15	39	66	107	82	22/03/2010
2011	438.99	1	9	30	53	93	77	17/03/2011
2012	582.22	3	16	41	79	104	111	20/04/2012
2013	521.62	3	10	36	69	107	89	29/03/2013
2014	283.75	1	3	16	45	78	73	13/03/2014

Year	Sum of rain-fall	Sum of rain 20mm	Sum of rain 10mm	Sum of rain 5mm	Sum of rain 2.5mm	Sum of rain 1mm	Start of rain (doy)	Start of rain (date)
2015	506.88	3	11	34	60	110	94	03/04/2015
2016	500.11	1	16	40	58	96	69	09/03/2016
2017	469.09	4	10	26	51	88	108	17/04/2017
2018	941.9	8	31	65	98	129	62	02/03/2018
2019	428.35	2	12	31	45	78	113	22/04/2019
2020	847.19	10	23	57	83	114	85	25/03/2020
2021	399.14	2	12	23	46	87	98	07/04/2021
2022	364.5	2	6	22	45	79	88	28/03/2022

Farmers need to know the sufficient amount of water they need in a season before planting their seeds and determine the most suitable planting date where rainfall distribution and amount suit the growth stage for their region by understanding the climatic conditions and using appropriate techniques. Sorghum crops have different stages of growth, and for high production, approximately 450–650 mm of water is required during the sorghum growth period [8]. The minimum rainfall threshold capable of sustaining sorghum crops ranges between 300 mm and 500 mm per year [9]. From the analysis of the long rainy season during the study years, 36.4% of the study period achieved high production, 42.4% sustained average production, and there was minimal or no production in 21.2% of the years. 2000 had the lowest with rainfall amount of 198.45 mm and extreme rainfall was noted in 2018 of 941.9 mm.

During the long rainy season as shown in the Table 3., the planting dates for the years 1991, 1996, 1999, 2000, and 2008 were not estimated because the 20mm rainfall accumulation over 3 days, without 9 consecutive dry days within 21 days of the start date was not attained. The same applies to the years 1990, 1993, 1996, 1998, 2000, 2003, 2016, and 2018 in the short season when the condition was not achieved, as shown in Table 5.

Table 4. Level of crop production with respect to water requirement.

Minimal production (<300mm)	Moderate (300-450mm)	High production (>450mm)
1992, 1993, 2000, 2006, 2008, 2009, 2014	1990, 1991, 1995, 1996, 1998, 1999, 2001, 2002, 2004, 2005, 2011, 2019, 2021, 2022	1994, 1997, 2003, 2007, 2010, 2012, 2013, 2015, 2016, 2017, 2018, 2020

Table 5. Summation of the rains at different intensity during the short season.

Year	Sum of rainfall	Sum of rain 20mm	Sum of rain 10mm	Sum of rain 5mm	Sum of rain 2.5mm	Sum of rain 1mm	Start of rain (doy)	Start of rain (date)
1990	105.82	0	0	3	14	40		
1991	137.13	0	0	6	21	48	248	04/09/1991
1992	172.34	0	3	7	27	61	250	06/09/1992
1993	93.48	0	0	1	5	37		
1994	178.84	0	1	9	24	63	310	05/11/1994
1995	190.17	0	3	11	27	64	249	05/09/1995
1996	98	0	0	1	13	47		
1997	299.61	0	3	18	48	77	292	18/10/1997

Year	Sum of rainfall	Sum of rain 20mm	Sum of rain 10mm	Sum of rain 5mm	Sum of rain 2.5mm	Sum of rain 1mm	Start of rain (doy)	Start of rain (date)
1998	135.91	0	0	8	18	50		
1999	130.45	0	1	5	15	47	334	29/11/1999
2000	130.82	0	0	2	24	50		
2001	211.77	0	2	11	35	66	304	30/10/2001
2002	214.67	0	3	10	32	67	275	01/10/2002
2003	150.85	0	0	7	22	58		
2004	183.57	0	2	6	29	64	308	03/11/2004
2005	157.33	0	3	11	26	38	252	08/09/2005
2006	357.34	1	11	22	43	82	252	08/09/2006
2007	162.2	0	0	16	22	47	253	09/09/2007
2008	261.99	1	5	15	38	61	278	04/10/2008
2009	221.76	0	2	17	35	58	282	08/10/2009
2010	192.69	0	2	12	26	53	262	18/09/2010
2011	416.92	2	10	29	48	74	248	04/09/2011
2012	352.93	1	6	28	48	75	248	04/09/2012
2013	255.74	1	4	16	29	66	249	05/09/2013
2014	198.64	0	2	10	28	63	246	02/09/2014
2015	378.55	2	8	20	46	92	307	02/11/2015
2016	160.55	0	0	6	25	60		
2017	348.97	3	7	24	38	66	245	01/09/2017
2018	168.14	0	1	7	25	56		
2019	499.4	2	13	34	66	95	245	01/09/2019
2020	398.84	1	6	23	41	73	250	06/09/2020
2021	233.03	0	1	9	38	79	262	18/09/2021
2022	254.17	0	3	14	40	69	250	06/09/2022

It should be noted that Tables 3 and 5. The number of days that received rainfall amounts at different intensities, that is, days that received more than 20 mm per day, 10 mm/day, 5 mm/day, 2.5 mm/day, and 1 mm/day. The onset of rainfall was determined by counting the number of days of the year (doy) and converting it to the actual date in that specific year.

In Baringo County, the planting period is heavily influenced by climatic conditions as well as specific varieties of crop seeds. The region has two rainy seasons: April - May and October - November. Therefore, land preparation usually occurs in February and March of every year. In some cases, land preparation was prolonged to early April. Several factors are involved in planting. One of the factors is the adequate moisture in the soil after the first week of rainfall. The amount of rainfall in an area determines its soil moisture content. Most ASALs areas experience prolonged dry seasons as they receive minimal rainfall. Therefore, farmers must wait for more rain to determine the suitability of the soil moisture content.

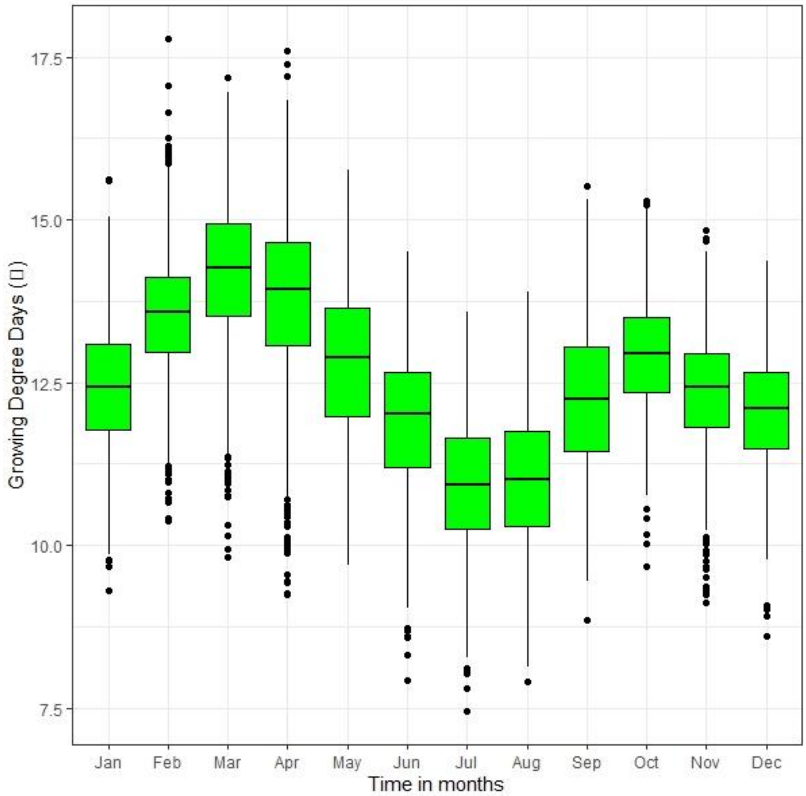

Figure 1. *Average growing degree days for the study period.*

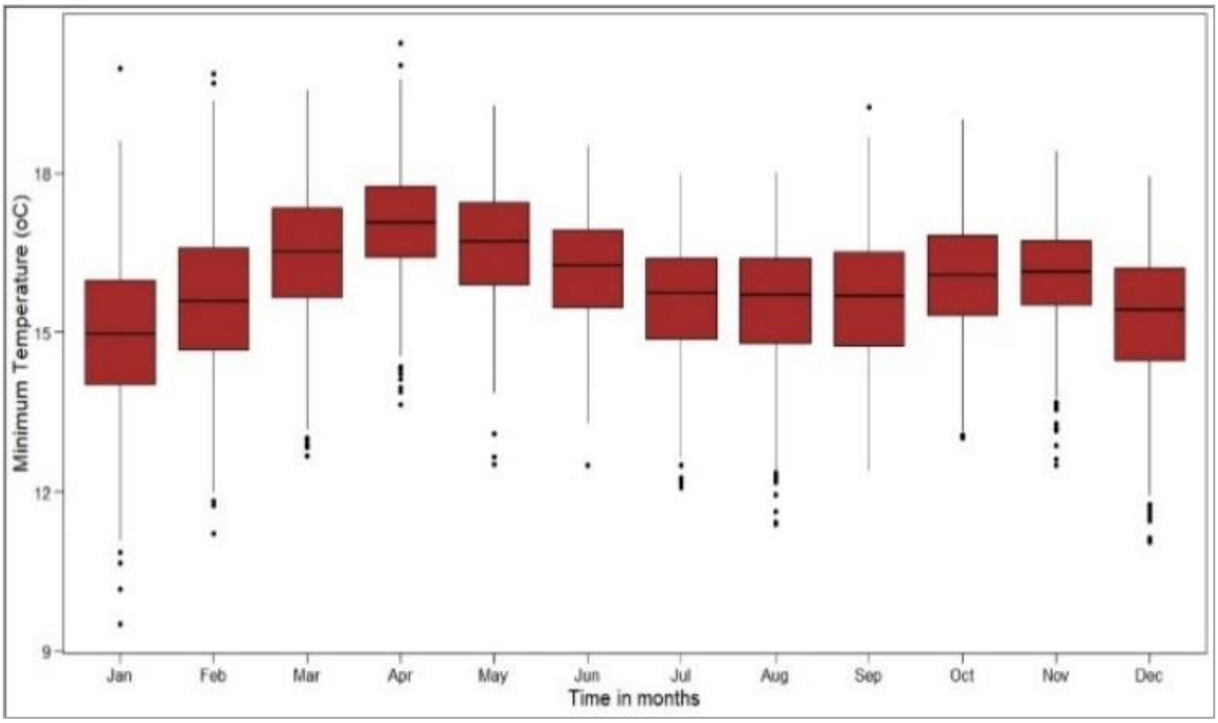

Figure 2. *Average minimum temperature for the study period.*

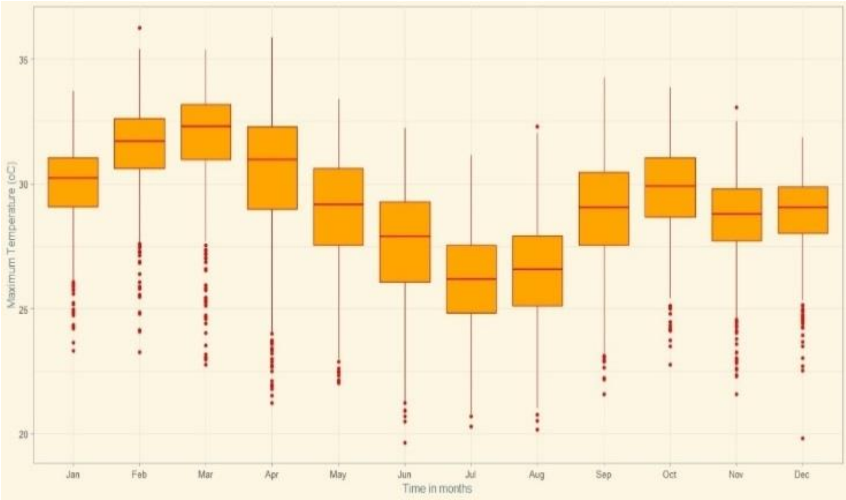

Figure 3. *Average maximum temperature for the study period.*

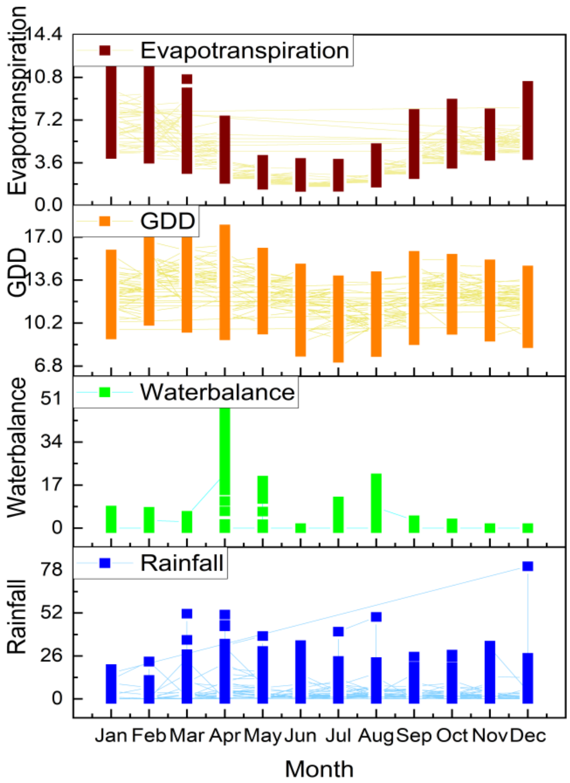

Figure 4. *Average monthly rainfall, water balance, GDD, and evapotranspiration.*

Growing degree days (GDD) have implications for crop selection and variety choice. Farmers choose crop varieties with specific temperature and precipitation requirements for optimal growth and development. These varieties can then be planted on dates that align with the temperature and water conditions required for successful growth. From Figure 4, it is evident that the months of April and May favour crop growth which can be favourable for the development stage. Evapotranspiration is lower in June meaning plants will lose less water. Hence, it may favour the flowering stage. In arid areas, changes in evapotranspiration are determined by the availability of soil moisture. However, in wet regions, the change in evapotranspiration is governed by energy availability [30]. Approximately 22% of sowings fail due to dry spells lasting at least seven days after the initial two-day wet spell with less than 10 mm of rainfall. Crop simulations show that sowing just after the first wet spell with at least 1 mm of rainfall in two consecutive days does not necessarily maximise yield because of the high risk of long-lasting dry spells after meteorological onset [20].

The short rainy season does not provide a suitable planting season for sorghum because most years have less accumulated rainfall to meet sorghum production. The average mean was 226 mm, although some years had more than 300 mm which could sustain sorghum production. 2006, 2015, 2019, and 2020, had 357.34mm, 378.55mm, 499.4mm, and 398.84mm consecutively. However, this is unreliable.

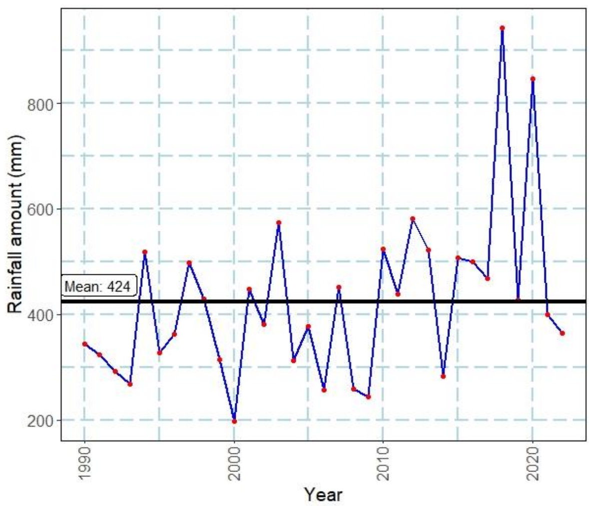

Figure 5. *Summation of the rainfall in the long rainy season.*

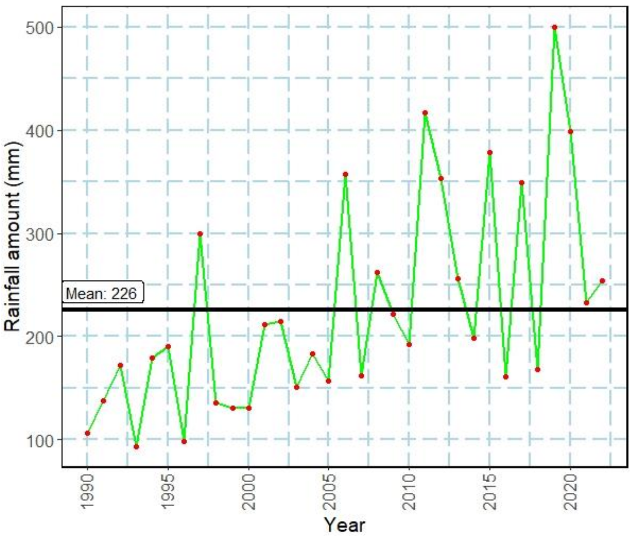

Figure 6. *Summation of the rainfall in the short rainy season.*

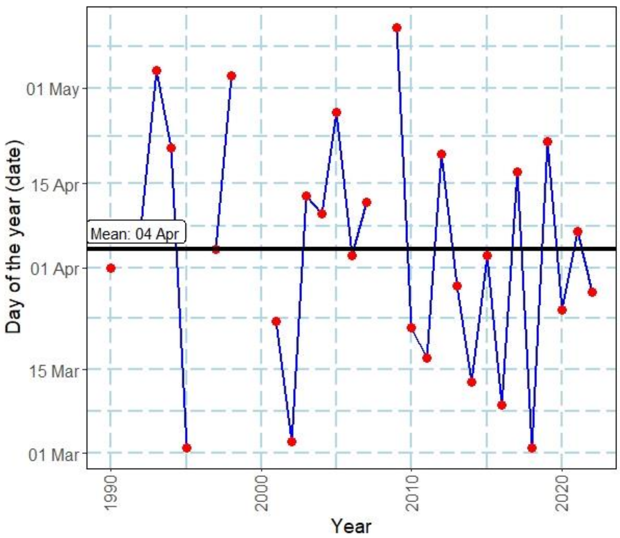

Figure 7. *Possible planting dates for the long rains.*

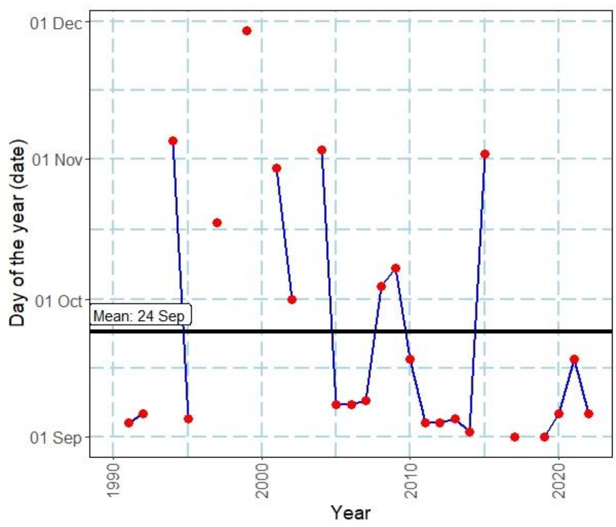

Figure 8. *Possible planting dates for the shot rains.*

Rainfall during the planting period is crucial for sorghum because it determines the germination, root establishment, and early growth of the crop. Insufficient rainfall during this period can lead to poor germination, stunted growth, reduced tillering, and an overall low yield potential. There is variability in the planting window in Baringo County, which falls far below and above the mean of 4th April for the long rainfall season and 24th September for the short rainfall season. Late onset was also noted in some years; for instance, in 1993 and 2009, the onset was on 4th & 11th May, the sum 267.68 mm and 243.22 mm consecutively which was not enough to sustain the crop for the growth season.

The provision of water to plants is greatly influenced by the commencement, duration, distribution, and conclusion of the rainy season, which can also serve as an indirect indicator of climatic suitability for crops and their likelihood of success or failure in a particular season. This study agrees with Kumi et al. (2023) in that the onset date has an influence on crop establishment and development. Determining the first planting date from climatic data is a crucial step in optimising crop production and ensuring agricultural sustainability. This allows farmers to make informed decisions about when to plant their crops. Farmers should be patient until 2.5 mm a day of rainfall is attained before commencing planting sorghum. However, for some cereals, such as maize, a threshold of 3.0 mm/day should be attained before commencing planting.

As an ASAL region, sorghum cultivation in Baringo relies heavily on adequate rainfall due to the sensitivity of the crop to moisture levels [8]. Evidence from the literature has indicated that the crop can do well with rainfall amounts ranging between 300 and 550 mm during the entire period of growth. Therefore, areas which receive less rainfall require alternative sources of water, such as irrigation.

4. Conclusion and Recommendation

Based on this study, it is evident that the most suitable time for planting is in late March and early April. These months experience the onset of rain, which helps provide sufficient moisture for successful sorghum cultivation. Based on observations, the crop's growth and development are intricately pegged to the availability of rain, which provides the moisture needed. Evidence from the literature has indicated that the crop can do well with rainfall amounts ranging between 300 and 550 mm for the entire period of growth. Therefore, areas which receive less rainfall require alternative sources of water for supplementary irrigation.

The analysis concluded that there was a variation in the onset of rainfall and seasonal summation. This shows that sorghum can do well during long rainfall periods, but improved varieties that require less water and have shorter growth seasons should be considered. The traditional method for determining onset dates was also shown to be unreliable in the Baringo region. Further studies are needed to evaluate the stability of different traits like drought- and heat-tolerant across multiple years and locations which implies that a long-term approach to studying the effects of planting date on sorghum yield could provide valuable insights for optimising planting schedules in other regions. Understanding the trigger points for sorghum planting is crucial for farmers and policymakers alike because it can contribute to informed decision-making in agricultural planning, resource allocation, and sustainable crop management practices.

Abbreviations

ASAL: Arid and Semi-Arid Land ASAL
CDD: Consecutive dry days
CV: The coefficient of variation
DOY: Day of the year
GDD: Growing Degree Days
IMD: Indian Meteorological Department
TAW: Total available soil water

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Conflicts of Interest

The authors declare no conflicts of interests.

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