

Optimizing Soil Drainage Strategies for Waterlogging Mitigation in Vertisol: Temporal Interventions for Lentil Production in Eastern Amhara Highlands, Ethiopia

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Abstract

In Ethiopia's central highlands, lentils are the second most important pulse crop, but their productivity is constrained by waterlogging and a lack of clear recommendations on optimal planting times. This study aimed to evaluate the effectiveness of various soil drainage techniques for lentil sowing, determine the optimal planting time for vertisols, and develop environmentally sustainable management strategies for lentil cultivation. Field experiments were conducted during the 2022 and 2023 cropping seasons in the eastern Ethiopian highlands, specifically in the Legehida and Wereilu districts of the Amhara region. The study tested three planting times (July, August, and September) and two land management practices (sowing with drainage on raised beds and sowing on flat beds) arranged in a factorial randomized complete block design (RCBD). The results showed highly significant differences in both locations. In Legehida, early planting on raised beds increased yield by 1004.78% and biomass by 642.13% compared to late planting. Yields were 1184.67% higher with raised beds than with flat beds or traditional farmer practices, which also showed a 541.86% increase in biomass. Similarly, in Wereilu, early planting on raised beds resulted in a highly significant improvement ($p \leq 0.05$) over farmer practices. Therefore, in vertisol areas prone to waterlogging, early sowing of lentils on 120 cm wide raised beds after drainage is an effective strategy to enhance yield and biomass production.

Keywords: lentil, planting date, soil drainage, vertisol management

Introduction

Ethiopia ranks among the top ten global producers of lentils (*Lens culinaris* Medik.) in terms of total cultivation area (FAO, 2022). Lentils are a vital cool-season food legume and have long-standing

importance for subsistence farmers, who rely on small-scale production for food, feed, cash income, and export earnings. The potential yield for lentils in Ethiopia is estimated at 1,400 kg.ha⁻¹ (CSA, 2021), with recorded yields reaching up to 1,500 kg.ha⁻¹ (FAOSTAT, 2016). Lentils are a staple in the daily diet of most households and are traded both locally and internationally, serving as a significant source of protein and a valuable source of income (Damte and Tafes, 2023). Lentil cultivation predominantly occurs at altitudes between 1,700 and 2,400 meters above sea level, where annual rainfall ranges from 700 to 2,000 millimetres (Abbas, 2022). In regions with higher rainfall, effective drainage is essential to prevent waterlogging, which can severely reduce yields and increase disease incidence (Wubie, 2015; Debele and Deressa, 2016; Lebay et al., 2021).

Both biotic and abiotic factors constrain lentil production. Among abiotic stresses, climate change poses a dynamic challenge, with severe or prolonged heat waves and droughts causing yield reductions through effects such as pod cracking (Choukri et al., 2020; Abbas, 2022). Despite these challenges, lentils are environmentally sustainable and well-adapted to diverse soil types, benefiting from biological nitrogen fixation that enriches soil fertility. As such, lentils play a crucial role in the farming systems and soil nutrition of Ethiopian subsistence farmers (Feleke, 2021; Kebede, 2020).

Sowing date is a critical agronomic factor for maximizing lentil seed yield. Optimal planting times vary depending on rainfall patterns, altitude, soil type, and cultivar maturity (Shah et al., 2021; Getachew, 2017). Generally, sowing is recommended between late June and mid-July on soils with low water retention, and between mid-July and mid-August on soils with higher water-holding capacity. In Ethiopia's central highlands, adhering to these sowing windows enhances lentil grain production (Alemayehu and Tesfaye, 2024). Supporting this, a recent field study in

the North Shewa Zone's Enewari area demonstrated that sowing lentils in early to late August on moderately heavy Vertisols significantly increased grain yields (Woldeselassie and Admasu, 2018).

An estimated 4.34 million hectares are used for lentil cultivation worldwide, resulting in an annual production of 4.95 million tons and a productivity of 1,260 kg.ha⁻¹, respectively (FAO, 2014). In Ethiopia, its production is not mechanized and is produced by smallholder farmers with fragmented plots of land mainly for household consumption (Dikshit et al., 2022). Ethiopia accounts for 81.5% of Africa's total lentil production and 69.4% of the land used for cultivation (FAO, 2014); the average lentil productivity in Ethiopia is approximately 1,230 kg.ha⁻¹ (CSA, 2021). The majority of Ethiopia's land is used for cultivating lentils, and both the yield and overall production volume have increased over time. The total area under production increased from 45,060 hectares in 1993 to 113,685 ha in 2016 (Bezabeh and Belay, 2019).

Ethiopian lentils are produced in the central highland plateau, primarily on black vertisol soils, but also on light and loam soils. Generally, well-drained soils with a nearly neutral pH are suitable for lentil production. Since vertisols mostly occur in highlands with adequate rainfall, challenges associated with them include waterlogging, which results in poor aeration, lower soil microbial activities, loss and unavailability of plant nutrients, and poor workability. Ethiopia has 12.6 million hectares of vertisol land, or approximately 10% of the country's total area, and ranks third in Africa for vertisol abundance, after Sudan and Chad. From 7.6 million ha (63%) of vertisol in the highlands, only 2 million ha (25%) were under cultivation. The present study area, comprising Legehida and Werillu, falls within this proportion.

Broad beds and furrows (BBF) and ridge and furrows (RF) are two enhanced surface drainage strategies that have been recommended. The beneficial impacts of these approaches on the agricultural productivity on vertisol have been well documented in Ethiopia. Accordingly, RF drainage outperformed flat planting for lentils in terms of grain output by 56% (Bejiga et al., 1996). In the same way, Erkossa et al. (2006) lentil (*Lens culinaris* Medik L reported that under BBF, lentil grain yield rose by 59% compared to flat planting.

In the study area, lentils are cultivated from the end of August to the beginning of September. They are sown broadcast-style in a level environment, which limits yield reduction. The farmers' production is almost insignificant. Thus, the primary objective

of the research is to assess the effectiveness of sowing lentils using various soil drainage techniques, determine the optimal planting time for vertisol, and provide environmentally sensitive management strategies for lentil production on vertisol.

Materials and Methods

Descriptions of The Study Area

The experiment was conducted during the main rainy seasons of 2022 and 2023 in the Wereilu and Legehida districts of the South Wello administrative zone, Amhara National Regional State, Ethiopia, located in the northeastern highland vertisol area (Figure 1). Wereilu district is geographically located between 10°20' 24" to 10°56' 10" N latitude and 39°22' 0" to 39°34' 0"E longitude and Legehida also geographical located in 10°34' 50" to 10°49' 57" N and 39°12' 0" to 39°23' 20" E latitude and longitude respectively and the altitude difference of both districts are ranges from 2200-3400 masl.

Based on the 10-year (2011–2020) climatic data, the area receives an average annual rainfall of 1786.09 mm, of which 74.6% is received during the primary rainy season (June to September). Most parts of Legehida have a very cold temperature, which ranges from 0 to 20 °C. The dominant soil in both districts is vertisol, characterized by black to gray clay with high swelling and shrinking properties. It is poorly drained when wet and cracks when dry. The lentil crop is predominantly planted next to wheat, tef, and faba beans.

Experimental Procedures

The treatments of the drainage method and the planting time (Table 1) were arranged in a randomized complete block design, with three replications on plots measuring 4.8 m in width and 4 m in length. Broad bed and furrow 120 was applied, which was adopted from Lebay et al., 2021a study was conducted to investigate the effects of soil drainage methods on surface runoff, soil loss, and yield of wheat crop as indicators of productivity improvement of typical Vertisol in the Jama district of Amhara Region, Ethiopia, during the rainy season of 2017/18. The treatment comprised three soil drainage methods (BBF120, BBF80, and BBF40. It was constructed manually by lifting the soil from two sides of the furrows and distributing it evenly on the upper part of the bed after the land was plowed with a traditional ox-drawn tine-plow implement having a 40 cm width. The effective growing area is 120 cm wide and 20 cm high, separated by 40 cm-wide furrows to facilitate

surface drainage between the beds. Crops are sown at the beginning of July, depending on the onset of rain and the type of crop to be grown.

Agronomic Practices and Data Collection

Tillage tactics were only used during planting. Since the soil at this time of year is not bulky or heavy enough for bed preparation, the beds and ridges were prepared during the first week of July, coinciding with the first rainfall. The locally adopted lentil (*Lens culinaris*) variety was sown at a rate of 70 kg.ha⁻¹ with a 20 cm row spacing, and twice by hand weeding within eight weeks of the seedlings emerging (Mitiku, 2016; DZARC, 2001). Recommended fertilizer rates for the study location kg.ha⁻¹ NPS were applied for all treatments (Woldeselassie et al., 2022). Agronomic data were obtained from the experimental plots by removing border effects, including biomass and

grain yield. A grain moisture analysis machine was used to further modify the yield of lentils with a 12.5% standard grain moisture, after acquiring grain yield and biomass data from the net plot under various treatments.

Soil data collection analysis

Using a soil auger, soil samples were taken from each experimental plot at depths ranging from 0 to 30 centimeters. The volume of the soil was then weighed, dried at 105 °C, and the percentage of soil moisture was calculated based on the weight loss. Due to the conflict, the data for the first agriculture season was not fully gathered. As a result, data on soil moisture changes caused by drainage were only collected and examined during the second year. Data on soil moisture were collected in the second year following the final sowing date, which occurred in

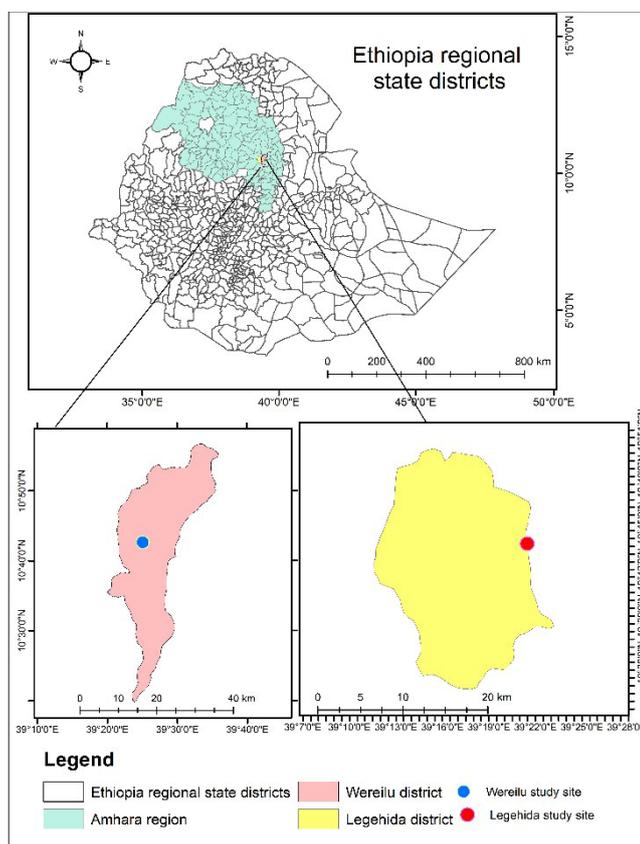


Figure 1. Location of the study area at Wereilu and Legehida districts in northeastern Ethiopia

Table 1. Treatment description

Types of drainage	Sowing dates
Raised bed and furrow: 120 cm bed and 40 cm furrow	First week of July
	End of July / first Week of August
Flat land	Local planting time is from the end of August up to mid-September

late August, at four-week intervals. The sample was collected using a soil collector can, and the amount of water content held in the soil was determined using the gravimeter method.

$$Smc (\%) = wsw - dsw * \frac{100}{dsw} - cw$$

Where, Smc = soil moisture content, wsw = wet of soil weight-dry soil weight, dsw = dry soil weight and cw = can weight

Data Analysis

To understand the impact of drainage and planting time on lentil yield and biomass production, the data were statistically evaluated individually at each location and in combination. SAS version 9.0 and Microsoft Office Excel 2013 were utilized for data analysis and management, respectively (Statistical Analysis System (SAS), 2004). Analysis of variance (ANOVA) was performed to test whether lentil yield and biomass production induced by treatments were statistically significant. Mean values were compared with the least significant difference test at $P < 0.05$.

Results and Discussion

The Effects of Soil Drainage Methods on the Lentil Yield and Biomass

In this experiment, treatments at the two research sites produced significantly different lentil yields and biomass amounts. Among the treatments, early planting of lentils on raised beds (120 cm wide) with 40 cm furrows was the most effective. Both sowing time and soil drainage had significant impacts on lentil yield and biomass, showing consistent results across both sites and agricultural seasons.

At the Legehida site, planting lentils on raised beds during the first planting period—the first week of July, coinciding with significant rainfall—resulted in substantially higher yields compared to planting on flat land at the same time. Overall, raised bed planting increased biomass production by 6.04% and yields by 43.87%. Similarly, sowing during the second planting period, around the first week of August, resulted in significantly higher yields and biomass on raised beds compared to flat beds. However, planting during the final sowing window—from the last week of August to the first week of September, which aligns with local farmers’ traditional schedule—resulted in very low or nearly lost production potential.

Comparing planting times, lentils sown early on raised beds and furrows outperformed the second planting time by 219.16% in yield and 162.86% in biomass. Additionally, early raised bed planting produced 110.18% more yield and 165.81% more biomass than flat land planting. The difference between early and late planting on raised beds was even more pronounced, with yield and biomass increases of 1004.78% and 642.13%, respectively, compared to late planting, and 1184.67% yield and 541.86% biomass increases compared to flat bed or local farmer practices.

Early lentil planting on raised beds (120 cm) demonstrated a substantial yield advantage over the national average lentil productivity, with increases of 35.25% in Legehida and 26.64% in Wereilu. The national lentil production potential is approximately 1,400 kg.ha⁻¹ (CSA, 2021), with recorded yields reaching up to 1,500 kg.ha⁻¹ in 2016 (FAOSTAT, 2016).

Notes: RBF1, RBF2 and RBF3= raised bed 1st, 2nd and 3rd planting time, respectively. B1, FB2 and FB3 = flatbed 1st, 2nd and 3rd planting time, respectively.

Table 2. Grain yield and biomass weight of lentil in Legehida district

Treatments	2022 Cropping season		2023 Cropping season		Combined over years	
	Grain yield (kg.ha ⁻¹)	Biomass (kg.ha ⁻¹)	Grain yield (kg.ha ⁻¹)	Biomass (kg.ha ⁻¹)	Grain yield (kg.ha ⁻¹)	Biomass (kg.ha ⁻¹)
RBF1	1494.0a	3316.0a	2293.1a	4930.6a	1893.6a	4123.3a
RBF2	1043.9b	2673.6c	142.8c	746.5c	593.3c	1568.6b
RBF3	129.9c	538.2e	154.2c	243.1c	171.4d	555.6c
FB1	918.1b	2427.1ac	1714.3b	3750.0b	1316.2 b	3888.5ab
FB2	1218.3ab	3125.0ab	206.5c	798.6c	712.4c	1961.8b
FB3	245.1c	1458.3d	108.4c	156.3c	147.4d	642.4c
CV	21.79	13.49	31.53	32.00	19.71	20.71

Notes: RBF1, RBF2 and RBF3= raised bed 1st, 2nd and 3rd planting time, respectively. B1, FB2 and FB3 = flatbed 1st, 2nd and 3rd planting time, respectively.

Similar to the Legehida study, the Wereilu trial concluded that planting lentils early and making a raised bed (120 cm) was more beneficial than other treatments. There is a considerable yield benefit to sowing lentils on the bed (120 cm) during the first planting period or during the first week of July. According to the average of two years' results, early sowing of lentils with raised beds (120 cm) might result in a 30.88% yield increase and a 19.19% increase in biomass production in Wereliu around the first week of July.

The amount of rainfall at Wereilu fell significantly from the last week of July during the second-year cropping season. The second and third plantings of lentil germination were impacted because the soil moisture content did not meet the requirements for lentil growth. As a result, no yield or biomass data have been collected at the second and third lentil

plantings, which have entirely failed.

Figure 2 shows the impact of drainage and planting time on the performance of Lentil at the vegetative stage. The first planting time or sown during July first week when the rain fall started and the soil have been witted crop sown on the bed is covered with the whole stand (1RB) and sown on the flat land also the plant stands not covered the entire plot (1FB) which impact on the yield and biomass production potential. Various studies conducted in similar agroecology and soil types have been consistent with these findings. The sowing date has varied with the pattern and total amount of rainfall, soil type, and maturity period of the specific crop cultivar, but in general, late June and mid-July are the recommended times for planting lentil in the central highlands of Ethiopia (Mitiku, 2016; (Getachew, 2001).

Table 3. Grain yield and biomass weight of lentil in Wereilu District

Treatment	2022 Cropping season		2023 Cropping season (2023)		Combined over years	
	Grain yield (kg.ha ⁻¹)	Biomass (kg.ha ⁻¹)	Grain yield (kg.ha ⁻¹)	Biomass (kg.ha ⁻¹)	Grain yield (kg.ha ⁻¹)	Biomass (kg.ha ⁻¹)
RBF1	2385.3a	5128.8a	1360.8a	2983.3a	1773.0a	3225.8a
RBF2	436.7c	1282.9bc	-	-	-	-
RBF3	670.0c	1060.0c	-	-	-	-
FB1	1395.0b	3801.5b	314.6 b	1145.8b	1354.7b	2706.3b
FB2	326.3c	1261.9bc	-	-	-	-
FB3	700.0c	1010.0c	-	-	-	-
CV	24.46	25.18	27.45	22.85	4.61	7.13

Notes: RBF1, RBF2 and RBF3= raised bed 1st, 2nd and 3rd planting time, respectively. FB1, FB2 and FB3 =flatbed 1st, 2nd and 3rd planting time, respectively.

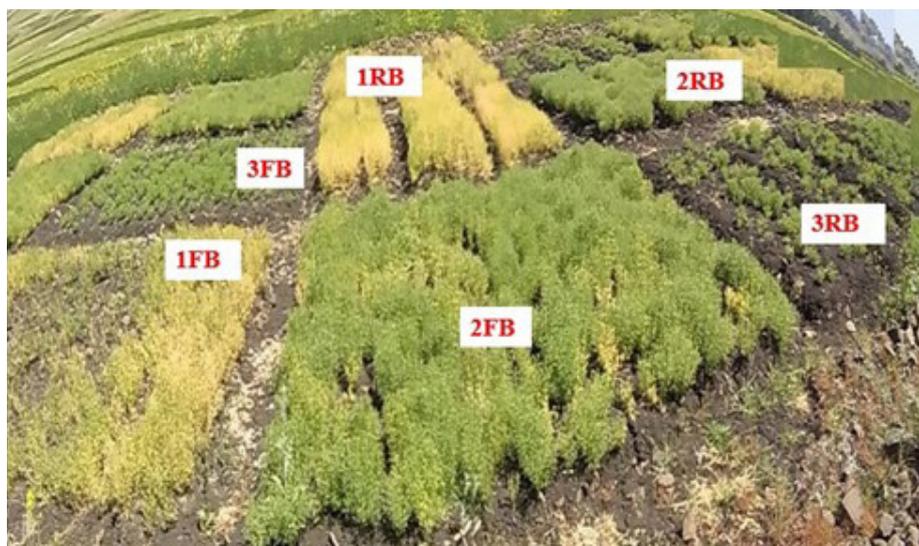


Figure 2. Lentil field performance in Legehida 2022 cropping season. RBF1, RBF2 and RBF3= raised bed 1st, 2nd and 3rd planting time, respectively.

Effect of Soil Drainage on the Soil Moisture Content

The data from the two consecutive months of the cropping season indicates that from August to September, the soil moisture content gradually dropped. The amount of soil moisture content is greatly impacted by raised beds and furrow soil drainage. It is concluded that surface runoff and rainfall are significantly influenced by soil drainage. Other studies also confirmed this finding. The proportion of rainfall lost to run off from, and is 55.05% for broad bed and furrow (BBF120), 51.45% for the broad bed and furrow (BBF80), and 48.07% for the broad bed and furrow (BBF40), in that sequence (Lebay et al.,

2021) a study was conducted to investigate the effects of soil drainage methods on surface runoff, soil loss, and yield of wheat crop as indicators of productivity improvement of typical Vertisol in the Jama district of Amhara Region, Ethiopia, during the rainy season of 2017/18. The treatment comprised three soil drainage methods (BBF120, BBF80, and BBF40. Lentil is mainly grown in the Ethiopian highland, where rainfall is usually high (Elias and Biratu, 2022). It is highly susceptible to excessive moisture stress; hence, farmers grow lentil on sloppy fields or use the ridge and furrow system to drain excess water from the lentil field, specifically from black soils (Feleke, 2021).

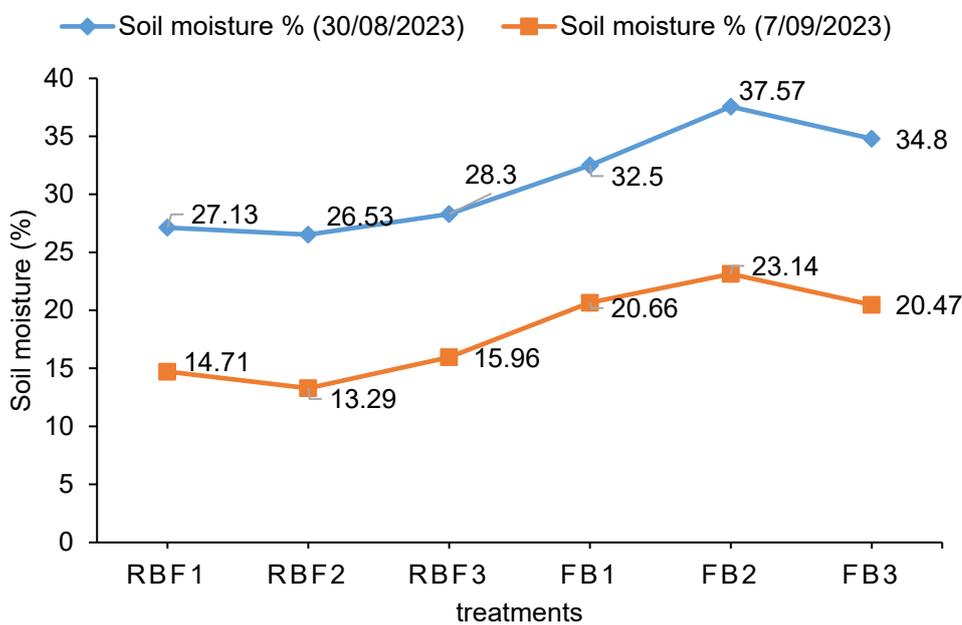


Figure 3. Soil moisture content 2023 in Legehida district. RBF1, RBF2 and RBF3= raised bed 1st, 2nd and 3rd planting time respectively. FB1, FB2 and FB3 = flatbed 1st, 2nd and 3rd planting time respectively.

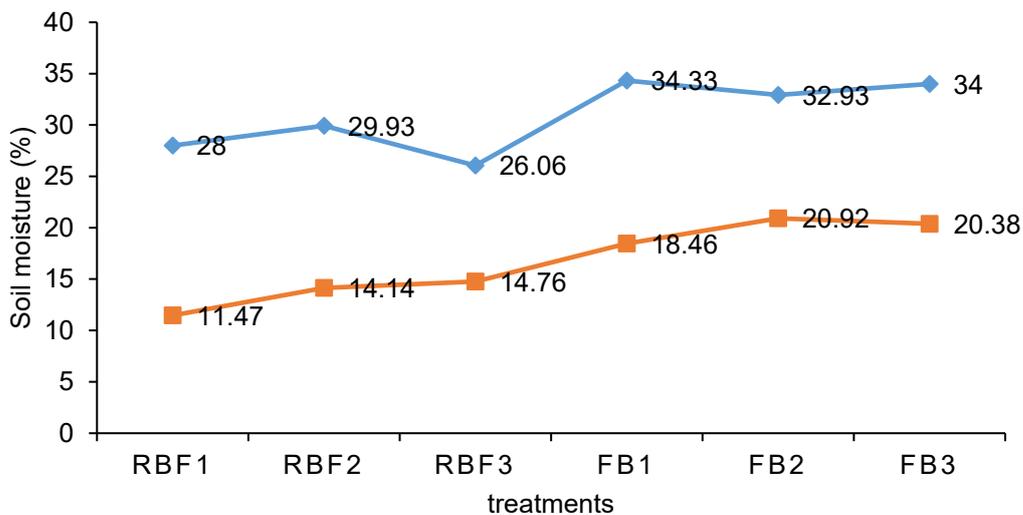


Figure 4. Soil moisture content in 2023 in the Wereilu district. RBF1, RBF2 and RBF3= raised bed 1st, 2nd and 3rd planting time respectively. FB1, FB2 and FB3 = flatbed 1st, 2nd and 3rd planting time respectively.

Change of Soil Moisture Content between the Raised Bed and the Flat Land

Figure 5 illustrates the amount of water drained from the field using the drainage technology. In this case, the excess rainfall has been removed from the field; for example, in Legehida, during the planting time of August, around 74% of the water was drained, and in Weriellu, also planting during the first week of July, drained the maximum amount of rainfall, which is around 60%. It is directly related to the amount of rainfall that the soil receives. The climatic data was taken from the neighboring meteorological sites, which are Wereilu, Jama, and Kelala meteorology sites. It indicates that the rainfall was gradually declining from July to September.

drainage is essential, as waterlogging will have a significant impact on yields and disease spread (Mitiku, 2016; Wubie, 2015). Severe or prolonged heat waves and droughts can also reduce yields by causing pod cracking. Among the major cool-season food legumes grown in Ethiopia, lentils are primarily cultivated between 1700 and 2400 meters above sea level, with an average annual rainfall of between 700 and 2000 mm (Woldeselassie et al., 2022). Planting late, the crop would be exposed to terminal moisture stress and frost damage (Chauhan and Ryan, 2020; Liu et al., 2021). If there is no frost and the rain continues throughout September and October, the harvest could be outstanding in favorable years. Since this frequently fails, the outcome may vary from a significant decrease in output to a complete crop failure (Debele and Deressa, 2016; Storr et al., 2021).

Lentils require a minimum of 350 mm of rainfall and a maximum of 550 mm; in higher rainfall areas, good

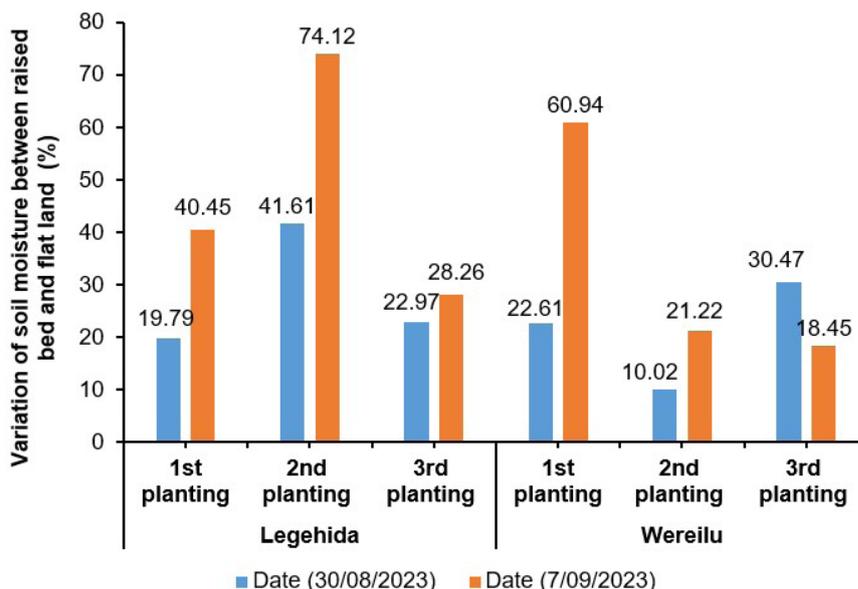


Figure 5. Changes in soil moisture (%) between the raised bed and the flat lands.

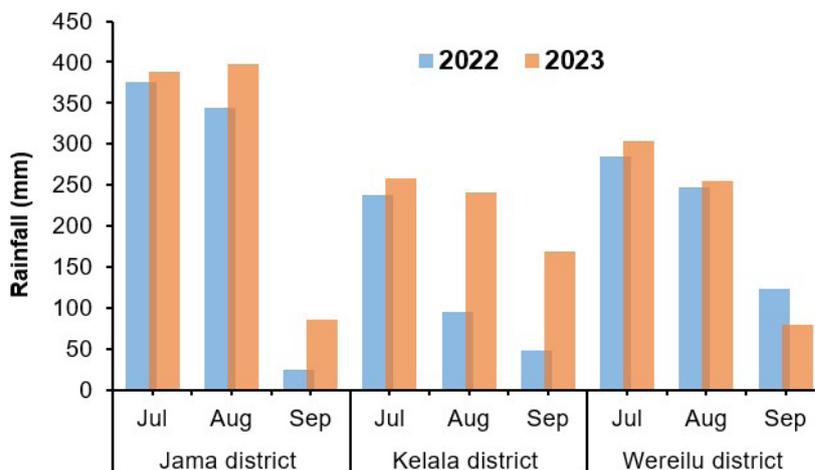


Figure 6. The average rainfall of the three months of the cropping season.

Conclusions

Significant differences were found in this study between planting lentils on raised beds and flat land, as well as between planting times assessed for the main agronomic factors considered. Additionally, drainage technology, which removes surplus water from fields and creates conditions favorable for lentil production, could affect the soil's moisture content. In Legehida, the drainage of a 120 by 40 cm bed and furrow, combined with early plating, resulted in a better yield and biomass, leading to an increase of 1184.67% in yield and 541.86% in biomass. In Wereilu, however, the last cropping season was lost entirely in the second year, although the first planting produced a yield of 1,773 kg.ha⁻¹ and biomass of 3,225.8 kg.ha⁻¹, respectively. For the vertisols of both Legehida and Wereilu areas, as well as other similar agroecologies, it is therefore advisable to produce lentils during the first week of July, when the rains are expected. In Legehida and Wereilu, the increase in lentil yield from national productivity was 35.25% and 26.64%, respectively.

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