Research Article

Evaluating the Effect of Cultivars and Seeding Rates on the Yield of Lentil Grown under the Vertisols Production System

Mebrate Tamrat Woldeselassie ⓘ,[1] Abel Gizaw,[2] and Simegnew Aniley[2]

[1]*Crop Research Directorate, Holetta Agricultural Research Center, P.O. Box 2003, Addis Ababa, Ethiopia*
[2]*Crop Research Directorate, DebreBirhan Agricultural Research Center, P.O. Box 112, Debre Birhan, Ethiopia*

Correspondence should be addressed to Mebrate Tamrat Woldeselassie; mebtam@gmail.com

Lentil is the second leading pulse crop grown in the central highland Vertisols of Ethiopia. However, waterlogging and the lack of situation-specific seed rate recommendations are among the problems that constrain its productivity. Therefore, a field experiment was conducted during 2017 and 2018 to determine the economically optimum seed rate for broadcast sowing of lentil varieties on Vertisols of North Shewa. Factorial combinations of two varieties of lentils ("Derash," large-seeded and "Local cultivar," small-seeded) and six seed rates (40, 60, 80, 100, 120, and 140 kg/ha) were tested in RCBD. According to the ANOVA results, the main effects of the environment, variety, and seed rate showed a significant effect on most parameters considered, except hundred seed weight for the environment, the number of seeds per pod for variety and plant height, and hundred seed weight for the main effect of seed rate. Lower yields were obtained in the second year due to the occurrence of sporadic unidentified disease, which might have created a confounding effect with variations due to the environment. The grain yield of variety "Derash" was best fitted to a power function, whereas "Local cultivar" showed a quadratic response with increasing seed rates ranging from 40 to 140 kg/ha. There was a positive and significant ($p < 0.001$) correlation between grain yield and each of the following: plant height, number of pods per plant, number of seeds per pod, and 100-seed weight. Based on ANOVA and economic analysis results, a seed rate of 100 kg/ha was found to be optimum for both varieties under the broad bed and furrow production systems on Vertisols.

1. Introduction

One of the oldest cultivated legume crops is lentils (*Lens culinaris* Medic.). Due to its valuable chemical composition and health-promoting properties, it is a desirable element of an everyday diet. Lentil seeds contain 24–32% of valuable protein and are also a rich source of phytoestrogens, folic acid, group B vitamins, and micronutrients [1]. In Ethiopia, it covers about 7.46% of the total pulse area and provides 5.88% of the pulse production [2]. It is almost a cash crop because it fetches very high prices compared with all other food legumes and main cereal crops such as tef, wheat, and barley [3]. The demand for this commodity, both in local and international markets, has increased significantly in recent years. It is often claimed that the internal (local) market seriously competes with the external market [4]. Moreover,

it offers an additional advantage emanating from its unique properties in restoring and maintaining soil fertility through symbiotic biological nitrogen fixation. Lentil can fix up to 107 kg of N/ha, implying a fixation of about 6,500 tons of N annually in Ethiopia. Consequently, Ethiopian lentil culture is characterized by growing the crop mainly in rotation with major cereals such as tef wheat, barley, and others. In such a culture, the yield advantage of the succeeding cereal crop is realized because of the fixed nitrogen by the predecessor legume and due to the breakage of the life cycle of important diseases and insect pests [5]. However, its average grain yield has remained low (1.37 t/ha) compared to 2.16 t/ha for faba beans and 2.01 t/ha for chickpeas (average of red and white types) [2]. This is due to several biotic factors (insects, diseases, and weeds) and abiotic factors (temperature, soil fertility, drought, waterlogging, and frosts) which affect the

production of lentils [5]. Waterlogging on Vertisols and a lack of specific plant density/seed rate recommendations are among the major yield-limiting constraints of the study areas. Moretina Jiru and Siyadebrina Wayu districts are among the areas where heavy clay soil (Vertisols) is dominant. In these areas, rainfall is high and the waterlogging problem is also more intense [6]. Therefore, waterlogging during the growing season impedes the performance of crops. Traditionally, farmers have been using handmade broad beds and furrows (HBBF–locally known as "Zekosh") to solve the waterlogging problem, though its high labor requirement is a constraint to its wider application. Studies on Vertisols indicated that draining excess water using broad bed and furrow (BBF) in Ethiopia resulted in increased yields of crops grown on Vertisols compared to flat-seeded [7]. According to Agegnehu [8], planting of lentils on BBF resulted in 106% grain yield and 78% straw yield increments over flatbed planting.

However, unlike flatbed practice under drained soil conditions, the production of crops under the BBF production system forces farmers to leave one-third of the land uncultivated for drainage purposes. Hence, this may require the recommendation of a specific seed rate (plant density) for lentil production under the BBF drainage system. It is also to be noted that the response to plant density varies among lentil genotypes/varieties depending on the seed size and growth habit of the specific cultivars [5]. For example, erect-growing and large-seeded genotypes need a higher seed rate, whereas prostrate and small-seeded ones need relatively lower seed rates [5]. Accordingly, several recommendations have been made within the country and around the globe to achieve optimum plant density. Saleem et al. [9] recommended a seed rate of 40–45 kg/ha for the production of small-to medium-sized lentil varieties around Islamabad and adjacent areas. On the other hand, Singh et al. [10] noted that, on average, sowing rates of 60 and 80 kg/ha increased the grain yield by 17% and 15%, respectively, over 40 kg/ha. Similarly, Morrison and Muehlbauer [11] recommended a seeding rate ranging from 67 to 79 kg/ha for the most commonly grown cultivar, "Brewer," for Palouse farmers in Washington State, the USA. In another study conducted in Southern Australia, a plant density of about 150 plants per square meter using a sowing rate of about 90–110 kg/ha was recommended depending on seed size and germination percentage of the seed [12]. In general, depending upon seed size, growth habit, planting time, and growing conditions, variable lentil sowing rates have been recommended around the globe, ranging from 20 kg/ha for a very small-seeded in Bangladesh [9] to 110 kg/ha for a large-seeded in Southern Australia [12]. However, according to a review by Saleem et al. [9], many studies show that lentil yields are remarkably stable over a wide range of population densities due to the ability of the plants to fill available space by initiating lateral branches and, thus, can compensate for poor emergence and thin stands.

For the sowing of lentils in rows in Ethiopia, a spacing of 20–25 cm between rows and 2.5–5.0 cm between plants has been recommended. On the other hand, the seed rate for the broadcast method appeared to vary depending on seed size

and growth habits. Accordingly, a larger seed size requires higher seed rates than a smaller seed size. Thus, a seed rate of 50–65 kg/ha for small-seeded, 65–80 kg/ha for medium-seeded, and up to 80–120 kg/ha for large-seeded lentil cultivars has been recommended on a blanket basis [13]. However, farmers in the study area are using higher seed rates (>100 kg/ha for all varieties) than the blanket recommendations. This is probably related to the absence of recommendations for broadcast planting of lentils on a broad bed and furrow production system where more field loss is expected. In addition, recommending the optimum seed rate for both large and small-seeded lentil varieties produced on Vertisols is crucial as they have different merits. The "Local cultivar" (small seed size) is preferred to prepare traditional food known as "Misir wot" or lentil stews (prepared from decorticated and split grains), as it tolerates higher heat than the improved variety "Derash" (large seed size) (personal communication). Hence, it is more preferred in the domestic market and fetches higher prices, while the improved variety is largely meant for the international market as it has a large seed size (personal communication). Therefore, these issues may necessitate the development of recommendations specific to heavy Vertisols. As a result, this study was initiated to determine the economically optimum seed rate for a broadcast sowing of lentil varieties on North Shewa Vertisols.

2. Materials and Methods

2.1. Site Description. Field experiments were conducted for two years (2017 and 2018) in Moretina Jiru and Siyadebrina Wayu districts, about 192 km and 177 km north of Addis Ababa, respectively, on relatively light and heavy Vertisol types as determined by farmers' experience during the main rainy season (from July to December). The experimental sites were located at latitudes ranging from $9^0 48'$N to $9^0 53'$N, longitudes ranging from $39^0 10'$E to $39^0 12'$E, and altitudes ranging from 2642 to 2665 meters above the sea level [14], as well as on-site records at Siyadebrina Wayu district). The sites were representative of the soils and environmental conditions used for lentil production in the recommendation domain.

2.2. Experimental Design, Treatments, and Plot Management. The treatments included a factorial combination of two varieties/cultivars of lentil ("Derash" and "Local cultivar") having different seed sizes (a 100-seed weight of about 3.42 g and 2.88 g, respectively) and six seed rates (40, 60, 80, 100, 120, and 140 kg/ha). Accordingly, a 2×6 complete factorial experiment was conducted in a randomized complete block design (RCBD) with three replications. A gross plot size of 4 m long and 4.8 m wide (19.2 m^2) was used. Two central beds (a net plot area of 9.6 m^2 (4 m long and 2.4 m wide)) were used for agronomic data collection and grain yield measurement. The space between replications and plots was maintained at 1.5 m and 1 m, respectively. Broadcast planting was exercised using a handmade broad bed and furrow (traditionally used by farmers) drainage system. In

this practice, raised beds of about 80 cm wide, separated by furrows of 40 cm wide and 15 cm deep, were established. This drainage system was done by the hand without the help of any tool, except that a dual oxen-drawn plow, the "Maresha," was used to open furrows at about every 1.2 m wide intervals. Handmade broad beds and furrows were made by the following sequential operations: first seeds were broadcast on the flat seedbed for each seed rate level in each plot, furrows were opened at every 1.2 m wide intervals using an oxen-drawn plow, and the soil was scooped out by the hand from the furrows to cover the seeds on the bed [15]. By doing so, four raised beds of about 80 cm wide, separated by furrows of 40 cm wide and 15 cm deep, were established in each plot. At the time of sowing, NPS chemical fertilizer at a rate of 121 kg/ha was applied uniformly to all experimental plots. Twice-hand weeding was undertaken to control weeds. Insect pests (aphids) were controlled by applying insecticides. Sowing was undertaken from the end of June to mid-August, while harvesting was undertaken from the end of December to mid-January in both years.

2.3. Sampling and Analysis of Soil. A composite soil sample was collected from five spots of the whole experimental field in a zigzag pattern from a depth of 0–30 cm before sowing. The sample was analyzed for selected physicochemical properties, mainly textural class (percent sand, silt, and clay), soil pH, total nitrogen, organic matter content, available phosphorus, and cation exchange capacity (CEC). The textural class was analyzed by the hydrometer method [16]. Soil reaction (pH) was tested by the potentiometric method [17]. Organic matter (OM) was determined by the Walkley and Black method [17]. A cation exchange capacity (CEC) was determined by a flame photometer [16]. Total N was determined using the Kjeldahl method [17], available P was determined using the Olson method [17], and exchangeable K was determined by a flame photometer [18].

2.4. Data Gathering and Measurements. Data collected on yield and yield-related traits consisted of days to flowering, days to physiological maturity, plant height, number of pods per plant, number of seeds per pod, 100-seed weight, and grain yield. Days to flowering were recorded when 50% of the plants in the plot produced their first flower, while days to physiological maturity were recorded when 90% of the plants in the plot reached physiological maturity. On the other hand, plant height, number of pods per plant, and number of seeds per pod were measured from 10 randomly selected plants from the central two beds of each plot. Plant height was measured in cm from the ground to the tip of the main stem at 90% physiological maturity. The number of pods per plant and the number of seeds per pod were measured at the time of harvest from 10 randomly selected plants. Grain yield was measured from the two central beds of each plot, while 100-seed weight was measured in grams as an average of two randomly counted 100-seed samples from each net plot after sun drying of threshed seeds.

2.5. Statistics, Regression, and Economics Analysis. Analysis of variance (ANOVA) was performed using GenStat version 16 and/or SAS Software version 9.0 [19]. The mean comparison was performed using Duncan's multiple range test (DMRT) at a 5% level of significance upon obtaining significant F values for the factors and interactions. The two-year data, i.e., three sites in 2017 and 2 sites in 2018 (mentioned as environments hereafter), were combined after obtaining variance homogeneity, which was tested by employing Bartlett's test [20].

The regression of grain yield of lentil varieties on seed rate was analyzed to see their relationship and fit the response curve. The curve fit was achieved by employing a stepwise selection technique (using polynomial terms) [20].

The economic analysis was performed on the mean predicted values of grain yield (derived from the fitted regression equation) following the methods of CIMMYT [21]. The field price was obtained by a simple assessment of farm gate prices near the experimental field immediately after harvest (December–February), which was taken as an average of two years. Accordingly, the prices of grain yield of "Derash" and "Local cultivar" were Ethiopian Birr (ETB) 28.00 and 30.00 per kg, respectively. The variable costs included the cost of seed during sowing (August) and were estimated at ETB 29.00 and 31.00 per kg for "Derash" and "Local cultivar," respectively. The cost of NPS fertilizer was not considered because it was applied uniformly to all plots [21]. The cost of labor for weeding, harvesting, threshing, winnowing, packing, and transporting of each treatment was not considered because of the difficulty in estimating it as the experiment was done on a small plot [21], and the differences were assumed to be negligible [22]. The average yield was adjusted downward to 10%, assuming a yield reduction of 10% if farmers managed the same on a larger plot. To use the marginal rate of return (MRR) as a basis for variety and seed rate recommendations, the minimum acceptable rate of return was set at 75% for both varieties/cultivars [21]. Treatment with higher costs that vary and lower net benefit than the preceding treatment was considered dominated and was eliminated from further consideration [21].

3. Results and Discussion

3.1. Experimental Sites' Soil Physicochemical Properties. As given in Table 1, the soil analysis of the study sites/environments revealed that the surface soil of all experimental fields was clay in texture. On average, the environments/sites were slightly acidic in pH (6.467), low in organic matter (1.23%), low in total nitrogen content (0.0803%), medium to high in exchangeable potassium (0.637 cmol (+)/kg soil), and high in cation exchange capacity (31.67 cmol (+)/kg soil) (soil lab results from Debre Berhan Agricultural Research Center, 2017).

3.2. Weather Conditions during the Crop's Growth Period. According to the unpublished data of the Ethiopian National Metrological Agency [22], the rainfall distribution and amount were lower for the year 2017 (676.1 mm) than for the

TABLE 1: Soil analysis results of Enewari and Deneba areas for the year 2017.

Parameter		Burtilik site	Deneba site	Farmer field	Mean value (mean ± SE)	Rating/soil reaction class
	Clay	70	68	68	68.67 ± 0.667	
Soil texture (%)	Sand	10	12	14	12 ± 1.155	
	Silt	20	20	18	19.33 ± 0.667	
Texture class		Clay	Clay	Clay	Clay	Clay
pH (1 : 2.5 H_2O)		6.36	6.60	6.44	6.467 ± 0.0706	Slightly acidic
OM (%)		1.03	1.64	1.02	1.23 ± 0.206	Low
TN (%)		0.074	0.094	0.073	0.0803 ± 0.00678	Low
Av. P (ppm)		n.d	n.d	n.d	n.d	n.d.
Ex. K (cmol(+)/kg soil)		0.59	0.63	0.69	0.637 ± 0.0296	Medium (at Burtilik) to high (at Deneba and farmer field)
CEC (cmol(+)/kg soil)		35.50	29.60	29.92	31.67 ± 1.916	High

SE, standard error of the mean; OM, organic matter; n.d, not determined; TN, total nitrogen; Av.P, available phosphorus; Ex. K, exchangeable K; CEC, cation exchange capacity. Source: Debre Berhan Agricultural Research Center Laboratory result.

year 2018 (772.2 mm). In 2018, there was rainfall from July to November with a decreasing trend, while there was no (negligible) rainfall after September in 2017 (Figure 1). Accordingly, the year 2018 seemed more favorable for lentil production, despite the damage caused by sporadic unidentified disease, which resulted in lower yields. The maximum temperature was higher in 2018 than in 2017 (except for July), and both showed an increasing trend after October (Figure 1). The mean minimum temperature showed a decreasing trend from August to December for 2018, while it lacked a trend for 2017 (Figure 1) [22].

3.3. Grain Yield and Agronomic Traits.
As stated in the methodology section, five environments (where environment one is denoted by the Burtilik site in 2017, environment two is denoted by the Deneba site in 2017, environment three is denoted by the farmer's field in 2017, environment four is denoted by the Burtilik site in 2018, and environment five is denoted by the Deneba site in 2018) were considered for the analysis and interpretation of the data.

3.3.1. Grain Yield.
As given in Table 2, ANOVA results showed a significant ($p < 0.05$) effect on the main effects of the environment, variety, and seed rate, as well as on the two-way interaction of the environment by variety, environment by seed rate, and on the three-way interaction of environment by variety by seed rate. The interactions with the environment (three-way and two-way) seemed highly significant, probably due to a confounding effect of the unidentified disease (that was identified as a viral disease after harvesting of the crop) problem in addition to environmental effects.

The three-way interaction was interpreted using the approaches suggested by Gomez and Gomez ([20], p.618). Accordingly, for the variety "Derash," both the highest and the lowest grain yield were recorded at the Deneba site in 2017 and 2018, respectively, at a seed rate of 120 kg/ha, while for the "Local cultivar," the highest grain yield was recorded at the Deneba site in 2017 at a seed rate of 140 kg/ha and the lowest grain yield was recorded at the Burtilik site in 2018 at a seed rate of 40 kg/ha (Figure 2). In general, for both varieties, the highest grain yield was recorded in the first year at

both localities and the lowest grain yield was obtained in the second year, while the farmer's field lies in between the two (Figure 2). The lower yields in the second year (2018) were probably related to the negative effect of the unidentified disease problem that occurred at both localities, affecting both varieties equally rather than the year effect [20]. If not, there was a higher and evenly distributed amount of rainfall in 2018, which might be favorable for the production of higher grain yields (Figure 1). The Deneba site, with its lower clay content, higher pH, higher OM, and higher total nitrogen, seemed to have more potential for lentil production (Table 1 and Figure 2).

Although the interaction between variety and seed rate was nonsignificant, stepwise polynomial regression chose a quadratic term for the variety "Local cultivar," while the variety "Derash" was the best fitted using the power function rather than linear regression due to a higher R^2 value (0.90**) for the power function (Figure 3). The equation became significant, probably due to varietal differences given in Table 2. In a similar experiment, Molla [23] fitted a significant stepwise regression equation, having significantly predicted terms for the nonsignificant NP interaction in the wheat fertilizer experiment. Based on the economic analysis results obtained from the predicted values obtained from a power function (Figure 3), a linear increase was observed for the variety "Derash," although it was not economical after a seed rate of 100 kg/ha (Table 3). At this seed rate, a net benefit of Ethiopian Birr 30379.52 and an MRR of 77.56% was obtained, while the minimum acceptable rate of return was set at 75%. On the other hand, the economic analysis for the "Local cultivar" was done using the predicted values obtained from a quadratic equation (Figure 3). Accordingly, the highest economic returns were obtained at a seed rate of 100 kg/ha with a net benefit of Ethiopian Birr 29732.00 and MRR of 108.60%, while the minimum acceptable rate of return was set at 75% (Table 4). In a similar manner, the mean grain yield across the varieties showed an increasing trend (by 28.04%) as the seed rate increased from 40 to 140 kg/ha, though it was insignificant from 100 to 140 kg/ha (Table 5).

Hence, depending on the ANOVA and economic analysis results, a similar seed rate of 100 kg/ha could be recommended for both varieties. In line with this result,
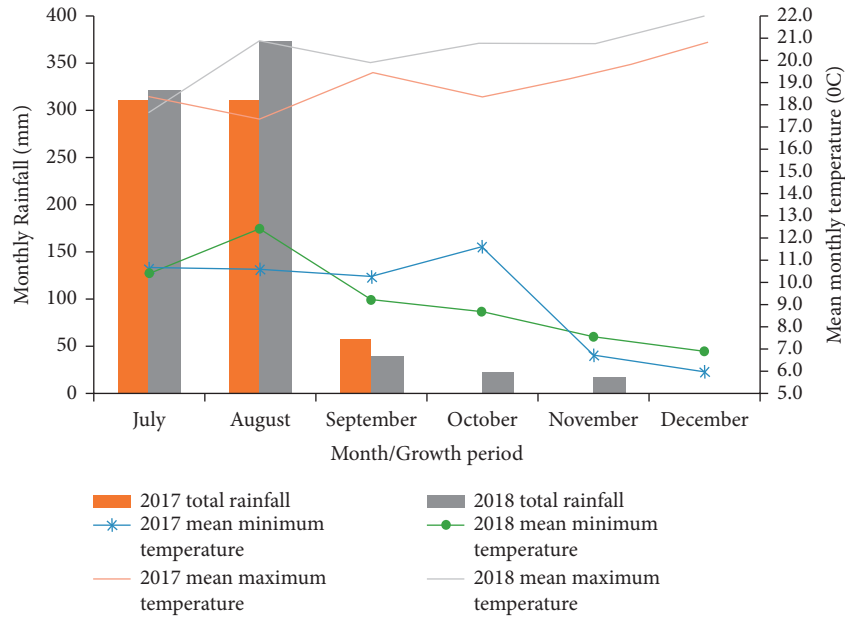
Figure 1: Rainfall (mm) and minimum and maximum temperatures for the growth period of lentils at Enewari. Source: National Meteorology Agency, Kombolcha branch directorate (unpublished data).

Table 2: Mean square values of ANOVA for grain yield of lentil as affected by variety/cultivar and plant density at Moretina Jiru and Siyadebrina Wayu districts, combined over five environments in 2017 and 2018.

Source of variation	d.f.	Grain yield
Replication (R)	2	0.15804
Environment (Env)	4	8.15999**
Variety (Var)	1	0.38617**
Seed rate (Sr)	5	0.33773**
Env.Var	4	0.53771**
Env.Sr	20	0.09121*
Var.Sr	5	0.01431 ns
Env.Var.Sr	20	0.10553**
Pooled error	118	0.04935

Siddique et al. [12] recommended a seed rate of 90–110 kg/ha in Southern Australia, depending on seed size and germination percentage of lentil seeds. The present results could also agree with the actual farmers' practice in those localities where they use higher seed rates (>100 kg/ha for all varieties) than the blanket recommendations mentioned in Mitiku [13].

3.3.2. Growth Parameters, Phenological Characteristics, and Yield Components. As was the case with grain yield, the environment showed a significant effect on most parameters considered, except 100-seed weight (Table 5). There was an extended flowering and maturity period in 2018 at Burtilik and Deneba sites that was probably attributed to higher and evenly distributed rainfall throughout the growth period of the lentil crop (Figure 1). Shorter plants were observed in 2018 at both the Burtilik and Deneba sites, probably due to the stunting effect of the disease (that was identified as a viral disease after harvesting of the crop) [24] that occurred in the second year. Similarly, fewer numbers of pods per plant were

recorded in the second year as the number of pods per plant showed a significant and positive association with plant height (Table 6). In contrast to the literature [25], the number of seeds per pod was influenced by the environment, where seeds per pod have been noted to be a component of yield that shows little variation across environments as it is linked more to genotype than to the environment.

The variety "Derash" took longer to flower and mature than the "Local cultivar." It also produced significantly taller plants, a higher number of pods per plant, a heavier 100-seed weight, and a higher grain yield than the "Local cultivar" (Table 5).

Concerning the seed rate, there was a linear and significant ($p < 0.05$) decrease in days to flowering, physiological maturity, and the number of pods per plant by 2.92, 1.9, and 85.35%, respectively, as the seed rate increased from 40 to 140 kg/ha (Table 5). Significantly, the highest number of seeds per pod was obtained at a seed rate of 100 kg/ha. The present findings on the number of pods per plant and the number of seeds per pod are quite similar to the results of Parveen and Bhuiya [26]. According to López-Bellido et al.
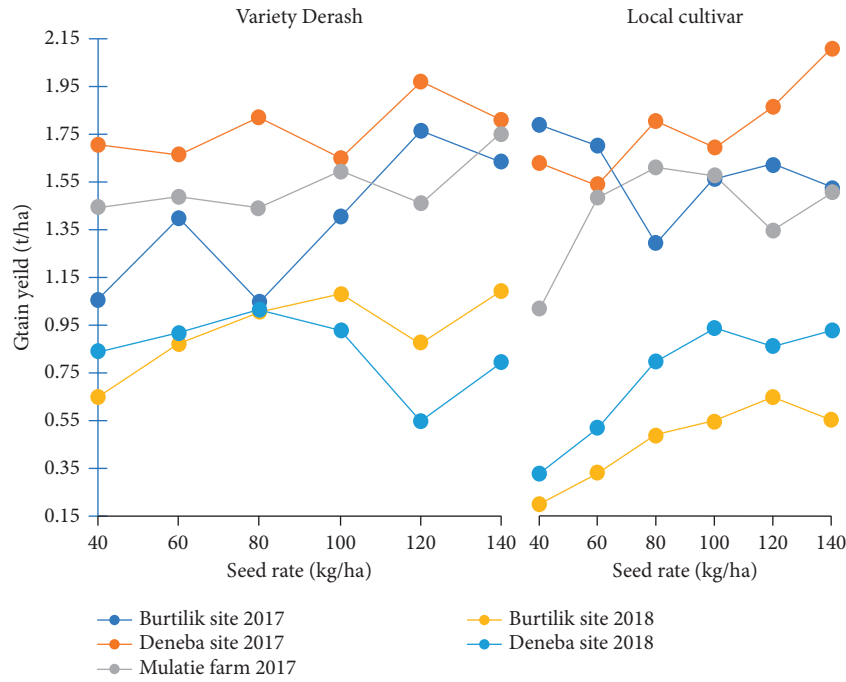
FIGURE 2: Effect of environment, variety, and seed rate on grain yield (t/ha) of lentil combined over 5 environments in 2017 and 2018.
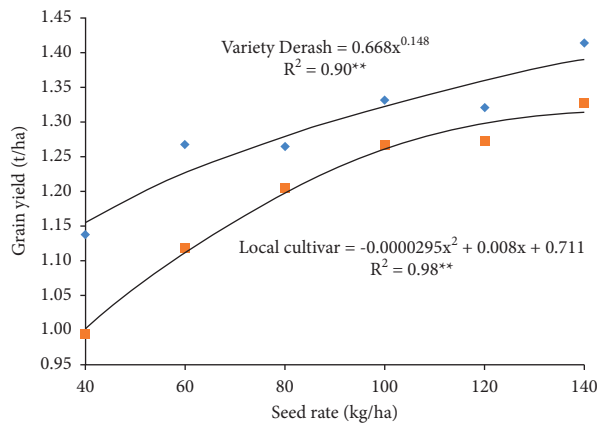

FIGURE 3: Regression equation between grain yield and seed rate for each variety (kg/ha). X represents the seed rate level.

TABLE 3: Dominance and marginal rate of return analysis for the effect of varieties of different seed sizes and seed rate on grain yield (t/ha) of lentil variety "Derash" at Moretina Jiru and Siyadebrina Wayu districts, combined over 5 environments (3 locations in 2017 and 2 locations in 2018).

Seed rate (kg/ha)	Predicted grain yield (kg/ha)	Adjusted grain yield (kg/ha)	GB (Birr/ha)	TVC (Birr/ha)	NB (Birr/ha)	MRR (%)
40	1.15	1.04	29059.08	1160.00	27899.08	
50	1.19	1.07	30034.79	1450.00	28584.79	236.45
60	1.22	1.10	30856.27	1740.00	29116.27	183.27
70	1.25	1.13	31568.32	2030.00	29538.32	145.54
80	1.28	1.15	32198.40	2320.00	29878.40	117.27
90	1.30	1.17	32764.60	2610.00	30154.60	95.24
100	1.32	1.19	33279.52	2900.00	30379.52	77.56
110	1.34	1.21	33752.28	3190.00	30562.28	70.29
120	1.36	1.22	34189.74	3480.00	30709.74	63.81
130	1.37	1.24	34597.17	3770.00	30827.17	57.98
140	1.39	1.25	34978.72	4060.00	30918.72	52.70

GB, gross benefit; TVC, total variable cost; NB, net benefits; MRR, marginal rate of return.

TABLE 4: Dominance and marginal rate of return analysis for the effect of varieties of different seed sizes and seed rate on grain yield (t/ha) "Local cultivars" of lentil at Moretina Jiru and Siyadebrina Wayu districts, combined over 5 environments (3 locations in 2017 and 2 locations in 2018).

Seed rate (kg/ha)	Predicted grain yield (kg/ha)	Adjusted grain yield (kg/ha)	GB (Birr/ha)	TVC (Birr/ha)	NB (Birr/ha)	MRR (%)
40	0.98	0.89	26562.60	1240.00	25322.60	
50	1.04	0.93	28005.75	1550.00	26455.75	365.53
60	1.08	0.98	29289.60	1860.00	27429.60	314.15
70	1.13	1.01	30414.15	2170.00	28244.15	262.76
80	1.16	1.05	31379.40	2480.00	28899.40	211.37
90	1.19	1.07	32185.35	2790.00	29395.35	159.98
100	1.22	1.09	32832.00	3100.00	29732.00	108.60
110	1.23	1.11	33319.35	3410.00	29909.35	57.21
120	1.25	1.12	33647.40	3720.00	29927.40	31.52
130	1.25	1.13	33816.15	4030.00	29786.15	D
140	1.25	1.13	33825.60	4340.00	29485.60	D

GB, gross benefit; TVC, total variable cost; NB, net benefits; MRR, marginal rate of return.

TABLE 5: Main effects of environment, variety, and seed rate on grain yield (t/ha) and some agronomic parameters of lentil combined over 5 environments in 2017 and 2018.

Treatment	DTF	DTM	Plh (cm)	NPPP	NSPP	HSW (g)	Gy (t/ha)
Environment							
Burtilik site in 2017	53.9[c]	105.0[cd]	30.2[a]	47.7[b]	1.5[a]	3.12	1.48[b]
Deneba site in 2017	54.2[c]	104.7[d]	31.0[a]	47.9[b]	1.3[b]	3.19	1.77[a]
Farmer field in 2017	54.5[c]	105.6[c]	31.0[a]	54.8[a]	1.5[a]	3.21	1.48[b]
Burtilik site in 2018	58.2[a]	108.4[a]	23.3[c]	26.1[d]	1.1[c]	3.14	0.69[c]
Deneba site in 2018	56.7[b]	107.6[b]	26.9[b]	35.4[c]	1.4[ab]	3.07	0.78[c]
LSD (5%)	0.508	0.70	1.08	3.33	0.12	ns	0.104
Variety							
Derash	57.1	112.2	31.2	47.0	1.3	3.42	1.29
Local cultivar	53.9	100.6	25.8	37.7	1.4	2.88	1.20
LSD (5%)	0.321	0.40	0.68	2.11	ns	0.066	0.066
Seed rate (kg/ha)							
40	56.4[a]	107.2[a]	27.6	58.2[a]	1.3[ab]	3.15	1.07[c]
60	56.0[a]	107.0[a]	27.9	48.3[b]	1.2[b]	3.21	1.19[b]
80	55.6[ab]	107.1[a]	28.6	42.7[c]	1.3[b]	3.09	1.23[b]
100	55.1[b]	105.7[b]	28.8	38.4[d]	1.5[a]	3.14	1.30[ab]
120	55.0[b]	105.5[b]	29.1	35.2[d]	1.3[ab]	3.17	1.30[ab]
140	54.8[b]	105.2[b]	28.8	31.4[e]	1.3[ab]	3.12	1.37[a]
LSD (5%)	0.556	0.80	ns	3.65	0.13	ns	0.114
Mean	55.5	106.3	28.5	42.4	1.3	3.15	1.24
CV (%)	2.00	1.40	8.13	16.80	18.70	7.10	17.90

DTF, days to flower; DTM, days to mature; NPPP, number of pods per plant; NSPP, number of seeds per pod; Plh, plant height; HSW, hundred seed weight; Gy, grain yield.

TABLE 6: Pearson's correlation coefficients between lentil grain yield and other studied characters, combined over 5 environments in 2017 and 2018.

	DTF	DTM	Plh	NPPP	NSPP	HSW	GY
DTF	—						
DTM	0.7588**	—					
Plh	−0.1248[ns]	0.328**	—				
NPPP	−0.0782[ns]	0.1667*	0.5164**	—			
NSPP	−0.2196**	−0.1037[ns]	0.1225[ns]	0.045[ns]	—		
HSW	0.4225**	0.6869**	0.4691**	0.2632**	−0.0159[ns]	—	
GY	−0.5076**	−0.15*	0.6041**	0.4024**	0.1718*	0.1679*	—

DTF, days to flower; DTM, days to mature; Plh, plant height; NPPP, number of pods per plant; NSPP, number of seeds per pod; HSW, hundred seed weight; GY, grain yield.

[25], under most environmental conditions, the number of pods per plant decreases with increasing density, compensating for the number of plants per square meter. The decrease in the number of pods per plant is due to a reduction in the number of stems per plant at higher densities. Plant height and 100-seed weight were not affected by seed rate (Table 5). Parveen and Bhuiya [26] reported a nonsignificant effect of seed rate on plant height and 1000 seed weight. Contrary to this result, Singh et al. [27] reported that increasing plant density increased the plant height of bold-seeded lentils.

In general, as given in Table 6, there was a positive and significant ($p < 0.001$) correlation between grain yield and each of the following: plant height, number of pods per plant, as well as number of seeds per pod and hundred seed weight. On the other hand, there was a negative and significant ($p < 0.001$) association between grain yield and each of the days to flowering and days to physiological maturity. This result reflected the importance of plant height, number of pods per plant, number of seeds per pod, and hundred seed weight in determining grain yield in the study areas. In line with this result, Tadele et al. [28] reported the presence of a positive association between grain yield and plant height of lentils on the Vertisols at Sinan. Similarly, Jawad et al. [29] reported a negative, nonsignificant correlation between grain yield and days to flowering and days to physiological maturity of lentils.

4. Conclusions

In this study, significant variation was observed between the varieties and among the seed rates tested for most of the parameters considered. Besides, environmental variation seemed significant due to sporadic unidentified disease incidence in the second year, resulting in lower yields. Depending on the ANOVA and economic analysis results, a seed rate of 100 kg/ha was found sufficient for the production of both varieties of lentils. However, producers who have limited access to resources could use a seed rate of 90–50 kg/ha in that order as an option for the broadcast sowing of lentil varieties on the highland Vertisols of the Moretina Jiru and Siyadebrina Wayu districts and similar areas under the broad bed and furrow production system.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there they have no conflicts of interest.

Acknowledgments

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