Optimizing Seeding Rates and Nitrogen and Phosphorus Fertilizer Rate for High Yield and Quality of Food Oats in the Central Highlands of Ethiopia

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Abstract

Food oats, one of the cereal crops meant both for grain and for feed, is an important crop in marginal ecologies. It can grow on a wide range of soil types and can perform better than other small-grain cereals on acid soils. However, no sufficient agronomic research recommendations are available to improve its productivity. Hence, an experiment was conducted in 2019 and 2020 cropping seasons to determine the optimum seed and fertilizer rate for higher yield and quality of food oats. Factorial combinations of seed rate (100, 125, and 150 kg/ha), nitrogen fertilizer (21, 42, and 63 kg/ha), and phosphate fertilizer (23, 46, and 69 kg P_2O_5/ha) were laid out in a randomized complete block design with three replications. Most of the interactions and the main effect of P_2O_5 fertilizer were non-significant for grain yield and hectoliter weight. The main effects of year, location, and seed rate showed a significant effect on both grain yield, and hectoliter weight, while nitrogen showed a significant effect only on grain yield. Grain yield linearly increased as the main effects of seed and nitrogen rate increased from the lowest to the highest level. All parameters were positively and highly significantly ($P<0.01$) correlated with or contributed to grain yield (except hectoliter weight). In general, a phosphorus fertilizer at the rate of 23 kg P_2O_5/ha together with a seed rate of 150 kg/ha and a nitrogen rate of 63 kg/ha was found to be optimum for food oat production on nitisols/red soils of the West and North Shewa zones.

Keywords: Cereal crops, North Shewa, Optimum, Quality, West Shewa

Introduction

Oat (*Avena sativa*) is a cool-season annual cereal crop abundantly grown in the central highlands, especially in the North Shewa and West Shewa Zones of Ethiopia. It also grows on a considerable scale in other parts of the country, like Arsi, Bale, and Gojam (Fekadu, 2018; Fikadu *et al*., 2021). Oat is one of the most nutritious cereals, high in protein, and well adapted to a wide range of soil types and can perform better than other small-grain cereals on acid soils (Mosissa *et al*., 2018). Though oats are mainly used as livestock feed, it has also been proved that the white-colored grain type can also be processed for human food. Hence, oat as a food grain has rapidly gained increasing popularity in recent years as a result of its serum cholesterol-lowering properties, thereby preventing heart-related problems (Price *et al*., 1987; Anderson *et al*., 1990). In Ethiopia, even though oats have been introduced for feed production purposes, resource-poor farmers eventually used the crop as a food grain (Fekadu, 2018). Despite the relative importance of oats in the above areas, they have traditionally been considered a low-input crop and are grown on low-fertile soils without any fertilizer application, hence, it grows poorly without the addition of nutrients. Studies conducted elsewhere showed a significant increase in oat grain yield and quality. For example, the application of nitrogen up to 80 kg/ha increased grain yields in different areas (May *et al*. 2004; Hamill, 2002). Similarly, Islam *et al*. (2020) recommended the application of 90 kg N/ha for oat production in Bangladesh. Gilchrist and Jack (2003) also reported a significant ($p<0.001$) drop in yield for each 20 kg/ha reduction in applied nitrogen from 100 kg/ha to 60 kg/ha. On the other hand, declines in test weight, kernel weight, and percent plump kernels, and increases in percent thin kernels have resulted from increasing N rates in several studies, such as May *et al*. (2004) and Mohr *et al*. (2007). Application of a P-containing seed coating often increased biomass production and grain set for oats but did not affect grain yield in Finland (Peltonen-Sainio *et al*. 2006). On the other hand, studies in Saskatchewan consistently demonstrated substantial increases in grain yield of oat with P fertilizer application regardless of the cultivar (Mitchell *et al*. 1953). Higher oat yields have been associated with greater plant tissue P concentration in P-deficient soils (Bolland and Brennan 2005).

Seeding rate is an important crop management practice that affects grain production and can be influenced by the type and fertility of the soil, climate, establishment methods (condition of seedbed and seeding method), and the like. Accordingly, several scholars reported different results in different areas and countries. Duda *etal*. (2021) suggested a seed rate of 125 to 175 kg/ha depending on the location and the purpose for which the crop is cultivated. Marwan *et al*. (2019) reported the highest grain yields from the highest seed rate (160 kg/ha). Similarly, Byamungu and Jo (2018) reported a linear increase in grain yield as the seed rate increased from 100 to 160 kg/ha. In Ethiopia, Dawit and Teklu (2014) reported the highest seed yield (4.48 t/ha) at a seed rate of 70 kg/ha and fertilizer rates of 50 kg Urea/ha and 100 kg DAP/ha for the production of fodder oats in the highlands of Bale, suggesting that the higher fertilizer rates could result in higher lodging of oat plants and also increasing seeding rates above 70 kg/ha are more likely to reduce the size and quality of seed.

Therefore, for higher yields and quality of oats, optimizing seeding rate and nutrient management (N and P fertilizer rate) should be considered as important factors when growing food oats. However, in Ethiopia and specifically in the study areas, information on best agronomic management practices, including seeding rate and nitrogen (N) and phosphorus (P) fertilizer recommendations suitable for acid-prone areas or other soil types are scanty. Hence, some producers are using the recommendations of food barley (DAP or NPS at a rate of 150 kg/ha and a seed rate of 150 kg/ha) for food oats production (MOA 2017). Therefore, this experiment was conducted to determine the appropriate seed and NP fertilizer rate and provide information for users.

Materials and Methods

Description of the experimental site

The field experiment was conducted at West Shewa Zone, Ejere and Wolmera Zuria districts and at North Shewa Zone, Degem district during 2019 and 2020 cropping season. The test locations' geographic coordinates were 9°3′ to $9^0$4' N latitude in the West Shewa Zone and $9^0$49' to $9^0$75' N latitude in the North Shewa Zone, 38°30′ to 38°41' E longitude in the West Shewa Zone and $38^0$37' to $38^0$52' E longitude in the North Shewa Zone, and an altitudinal range of 2337 to 2391 meters above sea level in the West Shewa Zone and 2705 to 3011 meters above sea level in the North Shewa Zone. Accordingly, the test sites in the North Shewa Zone lie at higher altitudes than those in the West Shewa Zone. The majorities of the North Shewa Zone areas have a mean annual rainfall of 800 mm to 1600 mm and mean annual minimum and maximum temperatures of 10 to 25 °C. In the West Shewa, the long-term average annual rainfall is 1100 mm while the average minimum and maximum air temperatures are 6.2 °C and 22.1 °C, respectively (Respective offices of agriculture, unpublished).

Soil characterization

A one kg composite soil sample was collected from the whole plot (from five spots) in a zigzag fashion to a depth of 0-30 cm just before sowing for determining soil pH, organic matter, total N, extractable P, exchangeable K, and cation exchange capacity (CEC). Soil pH was tested using the potentiometric method described by Tekalign (1991), organic matter was determined using the Walkley and Black method (Tekalign, 1991), total N was determined by the modified Kjeldahl method described by Tekalign (1991), extractable P was determined using the Bray II method described by Ankerman and Large (n.d.), exchangeable K was determined by the flame photometer described by FAO (2006), and CEC was determined by the flame photometer described by Hazelton and Murphy (2007). Only the first-year data is available for both localities (zones).

Treatments, experimental design, and procedures

The treatments included a complete factorial combination of three seeding rates (100, 125, and 150 kg/ha), three nitrogen levels (21, 42, and 63 kg N/ha), and three phosphate levels (23, 46, and 69 kg P_2O_5/ha). The treatments were arranged in a randomized complete block design (RCBD) with three replications. A gross plot size of 4 m^2 (1.6 m wide and 2.5 m long) with eight rows spaced 20 cm apart was used. Six central rows (a net plot area of 3 m^2) were used for phenological, yield, and yield component data collection. The alley space between plots and replications was kept at 0.5 m and 1 m, respectively. In all plots, P_2O_5 as triple superphosphate (46%) was hand drilled in a band at planting, while urea was hand drilled in a band one-third at planting and the remainder side dressed at the tillering stage of the crop.

The improved food oat variety, namely 'SORATAF' was used for this experiment. According to Fikadu *et al*. (2021), this variety is known to tolerate soil acidity problems and has better nutritional quality. It contains a high percentage of protein (16.0), fat (8.4), and ash (3.6). The high lipid (8.4 %) and mineral (156.35mg/L) content of this variety make it different when compared to other small-seeded cereals. The seeds were hand drilled into 20 cm spaced rows. The seedbed was plowed three to four times before planting. Two times, hand weeding was undertaken based on the severity of the weeds. Wheat and barley precursor crops were used in both years (2019 and 2020). Sowing was done on July 1, 2019 at the North Shewa Zone (Alidoro site), on July 24, 2019 at the West Shewa Zone (Chiree site), on June 11, 2020 at the North Shewa Zone (Degem site), and on July 24, 2020 at the West Shewa Zone (Sademo site). Harvesting by using sickles was done from the last week of December to mid-January in both years.

Crop data collection

The date of heading was recorded as the number of days from planting to a period when 50% of the spikelet produced heads. Date of physiological maturity was recorded as the number of days from planting to a period when 90% of the peduncles and spikes in a plot turn yellow. Plant height was measured from the ground level to the tip of the spike excluding the awns at physiological maturity from ten randomly selected mother plants (main shoots). The spike length was measured from the base to the top of the spike excluding awns from ten randomly selected mother plants (main shoots). Kernels per spike were taken as the average number of kernels per spike of 10 randomly chosen plants at harvest and expressed as the average number of kernels per plant. A thousand kernel weight was determined as the weight of 1000 seeds sampled from the harvested plot area using a sensitive balance. Grain yield was determined by weighing clean threshed seeds from the net plot area. The yield was adjusted to 12.5% grain moisture, which was determined using a grain moisture tester. Hectoliter weight (HL) (kg/hl) or test weight was determined as previously described by Buerstmayr *et al*. (2007).

Statistical analysis

Data were subjected to the analysis of variance (ANOVA) following the statistical procedure for three-factor factorial experiments using the General Analysis of Variance procedure of GenStat for Windows Version 16 (VSN International, 2013). The mean comparison was performed using the Duncan Multiple Range Test (DMRT) at a 5% level of significance upon obtaining significant F-values for the main effects and interactions. Two years' data were combined upon obtaining variance homogeneity, which was tested by employing Bartlett's test. Accordingly, a combined analysis of variance over years (2019 and 2020) and locations (hereafter termed as the West Shewa Zone and the North Shewa Zone) was performed for grain yield and agronomic parameters considered.

Economic analysis

The economic analysis was performed to investigate the economic feasibility of the average main effects of seed rate and N rates following the CIMMYT (1988) procedures. The field price was obtained by a simple assessment of farm gate prices near the experimental field after harvest (January to February), which was taken as the average of the two years, and the official prices of N and P fertilizers were used for economic analysis. Accordingly, the price of grain yield was estimated at 18.00 Ethiopian Birr (ETB) per kg. The variable costs included the cost of seed during sowing (June) and were estimated to be 20.00 ETB, while the official prices of N and P fertilizers were estimated at 33.00 and 34.00 ETB per kg, respectively. 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 plant density and fertilizer recommendations, the minimum acceptable rate of return was set at 100% (CIMMYT, 1988). A treatment having higher total costs that vary and a lower net benefit than the immediate preceding treatment with lower total costs that vary and a higher net benefit was considered to be dominated and was eliminated from further analysis.

Results and Discussion

The experimental site's soil physicochemical properties

As indicated in Table 1, in the year 2019, the pH of both experimental fields lies in the range of 4.27 to 5.07 and was found to be strongly acidic to very strongly acidic as rated by Tekalign (1991). According to Fekadu (2018), the variety under this study ('*SORATAF*') showed superior performance at different locations, having an exchangeable acidity range of 0.7-2.0 Meq/100g soil. The organic carbon of the experimental field lies in the range of 1.274 to 2.447%, which is classified as low to medium by Tekalign (1991). The total N percent in the experimental field was in the range of 0.16 to 0.21. According to Tekalign (1991), the total nitrogen content of the experimental soil lies in the moderate range. The extractable soil phosphorous lies in the range of 23.37 to 63.07 ppm, which is classified as low to very high (Ankerman and Large, n.d.), while the extractable K lies in the range of 1.64 to 1.659 [cmol (+)/kg soil], which is rated as very high (FAO, 2006). The CEC of the experimental fields lies in the range of 18.74 to 19.5 cmol (+)/kg and is classified as moderate (Hazelton and Murphy, 2007). CEC is used as a measure of soil fertility and nutrient retention capacity. Accordingly, soils high in CEC content are considered agriculturally fertile.

Phenological and growth parameters

The main effects of year, location, seed rate, and nitrogen, as well as the two-way interaction of year with location, location with seed rate, year with nitrogen, and location with nitrogen, all had a significant effect on days to 50% heading (Table 1). The earliest days to flowering were recorded in the first year (91 days) and at the West Shewa Zone (94 days) (Table 2), which is probably related to the elevation effect as the testing sites at the North Shewa Zone were at higher altitudes than those at the West Shewa Zone. In practice, crops grown at higher altitudes require longer durations than those at relatively lower altitudes. Due to competition for resources such as water, nutrients, and sunlight, days to heading decreased linearly by 1.06% as the seed rate increased from 100 to 150 kg/ha (Table 1). In line with this result, the increment in seed rate of malt barley from 100–175 kg/ha decreased the days to 50% heading by 6% (Senait *et al.*, 2020).

As nitrogen fertilization increased from 21 kg/ha to 63 kg/ha, the days to heading decreased linearly and significantly ($P<0.05$) from 97 to 93 days (Table 2). In contrast, while increasing levels of N fertilizer from control (0 kg N/ha) to the highest (54 kg N/ha), days to the heading of malt barley increased consistently (Terefe *et al*., 2018), which might be attributed to the behavior of increased N fertilizer that increases vegetative growth of crops, thereby delaying heading time. Phosphorus fertilization showed a non-significant effect on the days to heading, probably related to the presence of a sufficient amount of soil phosphorus, especially in the first year.

The interaction effect of location and seed rate on days to heading was significant ($P<0.05$) (Table 1). At West Shewa Zone, days to heading decreased linearly as the seed rate increased from 100 to 150 kg/ha, whereas there was little inconsistency at North Shewa Zone between seed rate two (125 kg/ha) and seed rate three (150 kg/ha) (Table 4). However, days to heading showed a decreasing trend while increasing seed rates, probably due to the enhancement effect of higher seed rates on days to heading due to competition for resources.

Days to 90% physiological maturity were significantly affected by the main effects of year, location, seed rate, and nitrogen, as well as by the three-way interaction of year, location, and nitrogen (Table 1). The earliest days to 90% physiological maturity were recorded in the first year (151 days) and in the West Shewa Zone (148 days) (Table 2). The days to 90% physiological maturity decreased linearly by 0.65% as the seed rate increased from 100 to 150 kg/ha (Table 2), which might be due to plant competition for available resources. In line with this result, time to kernel maturity decreased with the increasing seeding rate of malt barley (O'Donovan *et al.*, 2012). Similarly, increasing seeding rates of malt barley from 100–175 kg/ha decreased the days to 90% physiological maturity by 5 days (Senait *et al.*, 2020). As nitrogen fertilization increased from 21 kg/ha to 63 kg/ha, there was a linear and significant ($P<0.05$) decrease in days to maturity from 155 to 154 days (Table 3). In contrast, May *et al.* (2004) reported a non-significant but increasing trend as the N rate increased from 15 to 120 kg/ha for oats. Also, Terefe *et al.* (2018) reported contrasting results in malt barley.

The main effects of year, location, and nitrogen, as well as the two-way interaction of year with location, location with seed rate, a year with nitrogen, location with nitrogen, and the three-way interaction of year, location, and nitrogen, showed a significant effect on plant height (Table 1). Similarly, the five-way interaction of year by location by seed rate by nitrogen by phosphorus showed a significant ($P<0.05$) effect on plant height. Significantly taller plants (107 cm tall) were recorded in the first year and in the North Shewa Zone (109 cm high) (Table 2), which could be attributed to the presence of relatively higher soil total nitrogen and higher soil phosphorus availability in the first year. The tallest plants (107.4 cm high) were recorded at the highest N rate (63 kg N/ha) and the plant height increased linearly by 8.92% as nitrogen fertilization increased from 21 to 63 kg/ha (Table 2), which is probably because nitrogen promotes plant growth and increases the number of internodes and length of the internodes, which results in a progressive increase in plant height (Gasim, 2001). Similar results were obtained by Marwan *et al.* (2019), in which the tallest plants of oats were recorded at the highest nitrogen level of 80 kg/ha. Also, Islam *et al.* (2020) reported taller plants of oats for the highest rate of N applied (105 kg/ha).

Seed rate and phosphorus fertilization showed a non-significant effect on plant height. However, the interaction effect of location with seed rate and location with nitrogen was significant ($P<0.05$) on plant height (Table 1). From the results, the tallest plants (111.0 cm high) were obtained at a seed rate of 125 kg/ha at the North Shewa Zone, while no significant variation was observed between seed rates at the West Shewa Zone (Table 3). Similarly, there was a significant (P<0.05) variation between nitrogen levels at both localities, and the tallest plants (99.5 and 115.2 cm high, respectively) were obtained at the highest N rate of 63 kg/ha (Table 4). In a similar experiment, the highest plant height (134.2 cm) of fodder oats was recorded at the higher fertilizer level with a seed rate of 80 and 90 kg/ha, respectively (Dawit and Teklu, 2014). Yidersal *et al*. (2020) also reported taller plants of oats from the higher N and seed rate levels (a seed rate of 100 kg/ha and an N level of 150 kg/ha).

The spike length was significantly (P<0.05) affected only by the main effects of year and location and their interaction (Table 1). In contrast to the present result, Islam *et al.* (2020) reported a linear increase in spike length while increasing the N level from zero to 105 kg/ha. Significantly, the longest spikes (26.1 cm high) were recorded in the first year and the West Shewa Zone (26.3 cm high) (Table 2).

Yield and yield components

The number of seeds per spike was significantly (P < 0.05) affected by the main effects of year and nitrogen fertilization, as well as by the two-way interaction of year with location, a year with seed rate, and a year with phosphate fertilizer, and the three-way interaction of year by location by seed rate (Table 1). A significantly higher number of seeds per spike (65.4 and 60.6) was recorded in the second year and at the nitrogen fertilizer level of 42 kg/ha, respectively (Table 2). In contrast, Byamungu and Jo (2018) reported a higher number of grains per spike from the highest rate of N fertilizer (90 kg/ha). As discussed by Marwan *et al*. (2019), the number of grains per panicle increased linearly as the N rate increased from 0 to 80 kg/ha.

The main effects of year, location, and nitrogen, as well as the two-way interaction of year with location and seed rate with nitrogen, showed a significant (P < 0.05) effect on 1000 seed weight (Table 1). The heaviest 1000 seed weights (36.98 g, 37.23 g, and 36.35 g, respectively) were found in the second year, in the North Shewa Zone, and at the lowest nitrogen level of 21 kg/ha (Table 2). In agreement with this result, May *et al*. (2004) reported a decrease in the kernel weight of oats as the N rate increased. On the contrary, Marwan *et al*. (2019) and Islam *et al*. (2020) found that higher N rates resulted in a heavier 1000 seed weight of oats. On the other hand, Byamungu and Jo (2018) reported a non-significant effect of N fertilizer on the 1000 kernel weight of oats. As depicted in Fig. 1, the highest 1000 seed weight was obtained at the combination of a seed rate of 100 kg/ha with an N rate of 21 kg/ha, followed by a combination of a seed rate of 150 kg/ha with an N rate of 21 kg/ha which might be due to the vigorous seeds as lower intra competition in wider spacing. In contrary to this result, Byamungu and Jo (2018) reported a non-significant effect of seed rate with nitrogen interaction on 1000 seed weight of oat. Similarly, Zeki *et al*. (2005) also reported higher 1000 seed weight at the combination of higher N rates with lower number of seeds per square meter for triticale.

Table 1. Level of significance for grain yield and some phenological-and growth parameters of food oats as affected by seed rate, nitrogen, and phosphate fertilization in the West and North Shewa Zones, combined across years and locations

Source	DTH	DTM	Plh	SPL	NSPS	TSW	GY	HL
Year (Yr)	**	**	**	**	**	**	**	**
Location (Loc)	**	**	**	**	ns	**	**	**
Replication (R)	38.759	8.65	107.53	36.78	776.30	1.11	0.101	5.867
Seed rate (Sr)	**	**	ns	ns	ns	ns	**	*
Nitrogen (N)	**	**	**	ns	**	**	**	ns
Phosphorus (P2O5)	ns	ns	ns	ns	ns	ns	ns	ns
Yr.Loc	**	**	**	**	**	**	**	**
Yr.Sr	ns	ns	ns	ns	*	ns	ns	ns
Loc.Sr	*	ns	*	ns	ns	ns	ns	ns
Yr.N	**	ns	**	ns	ns	ns	ns	ns
Loc.N	*	ns	**	ns	ns	ns	ns	ns
Sr.N	ns	ns	ns	ns	ns	*	ns	ns
Yr.P2O5	ns	ns	ns	ns	*	ns	ns	ns
Loc.P2O5	ns	ns	ns	ns	ns	ns	ns	ns
Sr.P2O5	ns	ns	ns	ns	ns	ns	ns	ns
N.P2O5	ns	ns	ns	ns	ns	ns	ns	ns
Yr.Loc.Sr	ns	ns	ns	ns	*	ns	ns	ns
Yr.Loc.N	ns	*	*	ns	ns	ns	ns	ns
Yr.Sr.N	ns	ns	ns	ns	ns	ns	ns	*
Loc.Sr.N	ns	ns	ns	ns	ns	ns	ns	*
Yr.Loc.P2O5	ns	ns	ns	ns	ns	ns	ns	ns
Yr.Sr.P2O5	ns	ns	ns	ns	ns	ns	ns	ns
Loc.Sr.P2O5	ns	ns	ns	ns	ns	ns	ns	ns
Yr.N.P2O5	ns	ns	ns	ns	ns	ns	ns	ns
Loc.N.P2O5	ns	ns	ns	ns	ns	ns	ns	ns
Sr.N.P2O5	ns	ns	ns	ns	ns	ns	ns	ns
Yr.Loc.Sr.N	ns	ns	ns	ns	ns	ns	ns	ns
Yr.Loc.Sr.P2O5	ns	ns	ns	ns	ns	ns	*	ns
Yr.Loc.N.P2O5	ns	ns	ns	ns	ns	ns	ns	ns
Yr.Sr.N.P2O5	ns	ns	ns	ns	ns	ns	ns	ns
Loc.Sr.N.P2O5	ns	ns	ns	ns	ns	ns	ns	*
Yr.Loc.Sr.N.P2O5	ns	ns	*	ns	ns	ns	ns	ns
Residual	3.165	2.047	35.090	7.017	125.6	4.698	0.220	3.163

DTH=Days to 50% heading, DTM=Days to 90% physiological maturity, Plh=Plant height, SPL=Spike length, NSPS=Number of seeds per spike, TSW=Thousand seeds weight, HL=Hectoliter weight and GY=Grain yield

Table 2. The main effects of seed rate, nitrogen, and phosphate fertilization on grain yield and some agronomic parameters of food oats in the West and North Shewa Zones, combined across years and locations

Treatments	DTH	DTM	Plh (cm)	SPL	NSPS	TSW (g)	GY (t/ha)	HL (kg/hl)
Year								
2019	91	151	99	23.4	50.9	34.42	1.77	51.84
2020	99	158	107	26.1	65.4	36.98	3.15	48.72
LSD (5%)	0.4	0.3	1.3	0.58	2.45	0.475	0.103	0.39
Location								
West Shewa Zone	94	148	97	26.3	57.9	34.16	2.13	48.89
North Shewa Zone	95	161	109	23.2	58.4	37.23	2.79	51.68
LSD (5%)	0.4	0.3	1.3	0.58	ns	0.475	0.103	0.39
Seed rate (kg/ha)								
100	95	155	103.0	25.2	59.8	35.91	2.26	49.89
125	95	154	103.7	24.7	57.0	35.61	2.50	50.46
150	94	154	102.5	24.5	57.6	35.57	2.62	50.50
LSD (5%)	0.5	0.4	ns	ns	ns	ns	0.126	0.477
Nitrogen (kg/ha)								
21	97	155	98.6	24.3	54.7	36.35	2.19	50.12
42	95	154	103.2	25.1	60.6	35.28	2.42	50.28
63	93	154	107.4	25.0	59.1	35.47	2.77	50.45
LSD (5%)	0.5	0.4	1.6	ns	3.19	0.581	0.126	ns
P_2O_5 (kg/ha)								
23	95	154	103.0	24.7	57.9	35.66	2.46	50.32
46	95	154	103.7	24.9	58.7	35.48	2.43	50.22
69	95	154	102.5	24.8	57.8	35.94	2.48	50.31
LSD (5%)	ns	ns	ns	ns	ns	ns	ns	ns
Mean	94.7	154	103.1	24.8	58.1	35.7	2.46	50.28
CV (%)	1.9	0.9	5.7	10.7	19.3	6.1	19.1	3.54

DTH=Days to 50% heading, DTM=Days to 90% physiological maturity, Plh=Plant height, SPL=Spike length, NSPS=Number of seeds per spike, TSW=Thousand seeds weight, HL=Hectoliter weight and GY=Grain yield

Table 3. The two-way interaction effects of location with seed rate on days to heading, plant height, and hectoliter weight of food oats in the West and North Shewa Zones, combined across years and locations

Location	**Days to heading**			**Plant height (cm)**		
	Seed rate (kg/ha)			Seed rate (kg/ha)		
	100	125	150	100	125	150
West Shewa Zone	94.9ab	94.4b	93.4c	97.3c	96.3c	97.5c
North Shewa Zone	95.6a	94.9ab	95.0ab	108.7b	111.0a	107.5b
	Mean= 94.7, LSD (5%)= 0.7			Mean= 103.1, LSD (5%)= 2.20		

Table 4. The two-way interaction effects of location with nitrogen fertilization on days to heading and plant height of food oats in the West and North Shewa Zones, combined across years and locations

Location	**Days to heading**			**Plant height (cm)**		
	N rate (kg/ha)			N rate (kg/ha)		
	21	42	63	21	42	63
West Shewa Zone	96.5a	93.9c	92.4d	93.2e	98.4d	99.5d
North Shewa Zone	96.7a	95.1b	93.7c	104.0c	108.1b	115.2a
	Mean= 94.7, LSD (5%)=0.7			Mean= 103.1, LSD (5%)= 0.78		

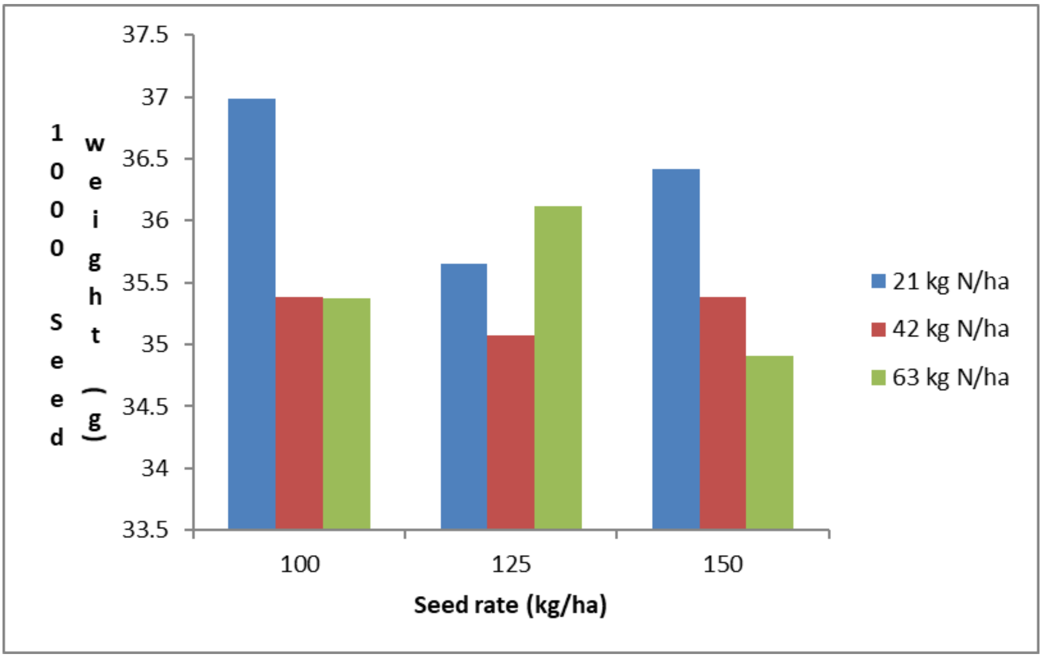

Figure 1. The combined effect of nitrogen fertilization and seed rate on 1000 seed weight (g) of food oats combined over years and locations

Grain yield was significantly affected by the main effects of year, location, seed rate, and nitrogen, as well as by the two-way interaction of year with location and by the four-way interaction of year by location by seed rate by phosphate fertilizer (Table 1). Significantly, the highest grain yields were recorded in the second year (3.15 t/ha) and in the North Shewa Zone (2.79 t/ha) (Table 2), most likely due to the presence of relatively higher soil total nitrogen and higher soil phosphorus availability in the first year. On the other hand, according to the results reported by Mohr *et al.* (2007), the response to phosphate in oats is inconsistent and often does not respond to soil test levels. In most cases, P fertilizer did not result in a significant increase in grain yield. Grain yield increased linearly by 15.93% as the seed rate increased from 100 to 150 kg/ha (Table 2). Similarly, as nitrogen fertilization increased from 21 to 63 kg/ha, there was a significant increase in grain yield from 2.19 to 2.77 kg/ha (Table 2). Also, the economic analysis revealed that the highest net benefits of 39444.00 and 42795.00 ETB/ha with marginal rates of returns of 298.29% and 718.18% were obtained under a seed rate of 150 kg/ha and a nitrogen fertilizer rate of 63 kg/ha, respectively (Table 5). Except for hectoliter weight, all parameters were positively and highly significantly ($P<0.01$) correlated with or contributed to grain yield (Table 6). In agreement with this result, Marwan *et al.* (2019) reported the highest grain yields from the highest nitrogen level (80 kg/ha) and the highest seed rate (160 kg/ha), justifying the contribution of the number of tillers per meter square, panicle length, and number of grains per panicle. Several scholars also reported different results. For example, Byamungu and Jo (2018) reported a linear increase in grain yield as the seed rate was increased from 100 to 160 kg/ha, while a higher grain yield was obtained at an N rate of 50 kg/ha. Islam *et al*. (2020) obtained the highest mean grain yield at 90 kg N/ha, but beyond 90 kg N/ha, the mean grain yield leveled off at a higher N rate (105 kg/ha), although the decrease was very slight. Also, Mohr *et al*. (2007) reported a higher grain yield at the higher N level of 100 kg/ha. Similarly, Gilchrist and Jack (2003) reported a significant ($p<0.001$) drop in yield for each 20 kg/ha reduction in applied nitrogen from 100 kg/ha to 60 kg/ha. In contrast, Dawit and Teklu (2014) obtained the highest seed yield (4.48 t/ha) at a seed rate of 70 kg/ha and fertilizer rates of 50 kg Urea/ha and 100 kg DAP/ha, suggesting that the higher fertilizer rates could result in higher lodging of fodder oats and that increasing seeding rates above 70 kg/ha are more likely to reduce the size and quality of seed.

Depending on both agronomic and economic analysis results, the highest grain yield was obtained from the highest seeding rate and nitrogen level. Hence, further study using higher seed and fertilizer rates needs to be considered, as the higher grain yield was obtained from higher levels.

Table 5. Dominance and marginal rate of return analysis for the effect of seed rate and nitrogen fertilization on grain yield (t/ha) of food oats in the West and North Shewa Zones, combined over years

Seed rate (kg/ha)	GY (t/ha)	GY adjusted (10% down) (t/ha)	GB (Birr/ha)	TVC (Birr ha^{-1})	NB (Birr ha^{-1})	MRR (%)
Seed rate (kg/ha)						
100	2.26	2.04	36634.84	2000.00	34634.84	
125	2.50	2.25	40452.53	2500.00	37952.53	663.54
150	2.62	2.36	42444.00	3000.00	39444.00	298.29
Nitrogen (kg/ha)						
21	2.19	1.97	35478.00	693.00	34785.00	
42	2.42	2.18	39204.00	1386.00	37818.00	437.66
63	2.77	2.49	44874.00	2079.00	42795.00	718.18

Table 6. Correlation coefficients between food oats studied characters

	DTH	DTM	Plh (cm)	SPL	NSPS	TSW (g)	HL (kg/hl)	GY (t/ha)
DTH	-							
DTM	0.563**	-						
Plh (cm)	0.296**	0.703**	-					
SPL	0.128*	-0.27**	0.022ns	-				
NSPS	0.202**	0.105ns	0.228**	0.575**	-			
TSW (g)	0.496**	0.668**	0.545**	-0.217**	-0.051ns	-		
HL (kg/hl)	-0.465**	0.130*	0.043ns	-0.306**	-0.059ns	-0.218**	-	
GY (t/ha)	0.521**	0.633**	0.743**	0.173**	0.353**	0.5024**	-0.125*	-

DTH=Days to 50% heading, DTM=Days to 90% physiological maturity, Plh=Plant height, SPL=Spike length, NSPS=Number of seeds per spike, TSW=Thousand seeds weight, HL=Hectoliter weight and GY=Grain yield

Quality parameters

The hectoliter weight/test weight, which is a measure of the density or specific weight and is thought to be an indicator of grain quality, particularly potential extract yield (Burke *et al*., 2021), was significantly affected by the main effects of year, location, and seed rate, as well as by the two-way interaction of year with location, and by the three-way interactions of year by seed rate by nitrogen, and location by seed rate by nitrogen, as well as by the four-way interaction of location by seed rate by nitrogen by phosphate fertilization (Table 1). Significantly, the heaviest hectoliter was recorded in the first year (51.84 kg/hl) as well as in the North Shewa Zone (51.68 kg/hl) (Table 2). It increased linearly by 1.22% as the seed rate increased from 100 to 150 kg/ha, but the difference between seed rates of 125 and 150 kg/ha was not significant (Table 2). In contrast, increasing seeding rates from 100–175 kg/ha linearly decreased the hectoliter weight of malt barley (Senait *et al.*, 2020). Nitrogen and phosphorus fertilization showed a non-significant effect on hectoliter weight. However, the heaviest hectoliter was obtained at the North Shewa Zone at all seed rates and nitrogen fertilization levels, as shown in Table 7.

The highest/heaviest hectoliter was recorded at the combination of the North Shewa Zone with a seed rate of 125 kg/ha and a nitrogen fertilization rate of 21 kg/ha, while the lowest hectoliter weight was recorded at the combination of the West Shewa Zone with a seed rate of 100 kg/ha and a nitrogen fertilization rate of 21 kg/ha. From the results, it can be concluded that the North Shewa Zone could be more favorable for producing quality seeds. In practice, food oats are widely produced in the North Shewa zone, where the altitudes are higher and cooler than in the West Shewa zone. In general, as stated above, the hectoliter weight is a common measure of grain quality in oats (*Avena sativa* L.), and it measures the weight per unit volume of grain and is positively associated with nutritional value and milling quality (Pixley, 1990). On the other hand, the quality of oat grain depends on genetic factors and environmental conditions throughout the growing season (Peterson *et al*., 2005, Zeki *et* *al*., 2018). According to the codex quality standards (1995), the minimum acceptable test weight for oats is at least 46 kg/hl. Accordingly, the results of the present experiment demonstrated an acceptable test weight for both zones, but preferably at the North Shewa None (Tables 2 and 7).

Table 7. The three-way interaction effects of location by seed rate by nitrogen fertilization on hector liter weight (kg/hl) of food oats in the West and North Shewa Zones, combined over years and locations

Location	Seed rate kg/ha	Nitrogen (kg/ha)	Hectoliter weight (kg/hl)
West Shewa Zone	100	21	48.29c
West Shewa Zone	125	21	48.44c
West Shewa Zone	150	21	49.16c
West Shewa Zone	100	42	48.81c
West Shewa Zone	125	42	48.87c
West Shewa Zone	150	42	48.97c
West Shewa Zone	100	63	48.99c
West Shewa Zone	125	63	49.14c
West Shewa Zone	150	63	49.32c
North Shewa Zone	100	21	51.51ab
North Shewa Zone	125	21	52.52a
North Shewa Zone	150	21	50.81b
North Shewa Zone	100	42	50.90b
North Shewa Zone	125	42	51.89ab
North Shewa Zone	150	42	52.22a
North Shewa Zone	100	63	50.87b
North Shewa Zone	125	63	51.89ab
North Shewa Zone	150	63	52.49a

Conclusions

In the present study, seed rate and nitrogen rate showed a significant effect on most of the studied parameters, while phosphate fertilization had no significant effect on all the studied parameters. Based on higher agronomic and economic yield, the lowest phosphate fertilizer rate of 23 kg P_2O_5/ha together with a seed rate of 150 kg/ha and nitrogen rate of 63 kg/ha was found to be optimum for food oat production in the West and North Shewa Zones. In addition, further study needs to consider using a zero phosphate fertilizer rate and higher seed rates and nitrogen levels.

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