OCL 2023, 30, 3
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https://doi.org/10.1051/ocl/2023001

OCL Oilseeds & fats Crops and Lipids

Available online at:
www.ocl-journal.org

RESEARCH ARTICLE OPEN ACCESS

Response of oil producing camelina (*Camelina sativa* L.) crop to different agroecology and rate of NP fertilization☆

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Received 22 September 2022 – Accepted 10 January 2023

Abstract – Camelina (*Camelina sativa* L.) is an industrial crop, which has been cultivated for centuries as an oilseed crop for human food, however, the production and its importance were not well known in Ethiopia. The current research was conducted to identify potential agroecology and rate of NP (nitrogen and phosphorous) fertilizer for the high yield production of camelina crop. Two major agroecological zones, namely highland (moist dega) and midland (moist weyna-dega) agroecologies, were tested. The experiments in both agroecology were conducted in RCBD design with similar treatments. The treatments were (T1 = 0 kg N ha^{-1}, 0 kg P ha^{-1}), (T2 = 30 kg N ha^{-1}, 10 kg P ha^{-1}), (T3 = 60 kg N ha^{-1}, 20 kg P ha^{-1}), (T4 = 90 kg N ha^{-1}, 30 kg P ha^{-1}), (T5 = 120 kg N ha^{-1}, 40 kg P ha^{-1}) and (T6 = 150 kg N ha^{-1}, 50 kg P ha^{-1}). Significant ($P < 0.05$) differences were observed among the fertilizer treatments. Accordingly, in highland, the highest seed weight (8.37 g $plant^{-1}$) and grain yield (1814.54 kg ha^{-1}) were recorded from T5, while in midland, the highest seed weight (3.89 g $plant^{-1}$) and grain yield (843.97 kg ha^{-1}) were recorded from T6. The highest aboveground biomass (32.08, 18.49 g $plant^{-1}$) and plant height (102.34, 86.33 cm) were recorded from T6 in highland and midland agroecology, respectively. According to the Pearson's correlation analysis, significant ($P < 0.001$) positive correlation was observed between the plant height, seed weight, aboveground biomass and grain yield. In general, highland agroecology showed 115%, 18.53%, 114.95% and 73.53% increase in grain yield, plant height, seed weight, and aboveground biomass, respectively as compared to midland agroecology.

Keywords: camelina / NP fertilizer / moist dega / moist weyna-dega / habitat

Résumé – Réponse de la culture oléagineuse de caméline (*Camelina sativa* L.) à différentes agroécologies et à différents taux de fertilisation NP. La caméline (*Camelina sativa* L.) est une culture industrielle, qui est cultivée depuis des siècles comme oléagineux pour l'alimentation humaine, mais sa production et son importance ne sont pas bien connues en Éthiopie. La présente recherche a été menée pour identifier l'agroécologie potentielle et le taux d'engrais NP (azote et phosphore) assurant une production à haut rendement de la culture de caméline. Deux grandes zones agroécologiques, à savoir l'agroécologie des hauts plateaux (zone climatique du dega humide) et celle de zones intermédiaires (weyna-dega humide), ont été testées. Les expériences dans les deux agroécologies ont été menées selon un plan RCBD avec des traitements similaires. Les traitements étaient (T1 = 0 kg N ha^{-1}, 0 kg P ha^{-1}), (T2 = 30 kg N ha^{-1}, 10 kg P ha^{-1}), (T3 = 60 kg N ha^{-1}, 20 kg P ha^{-1}), (T4 = 90 kg N ha^{-1}, 30 kg P ha^{-1}), (T5 = 120 kg N ha^{-1}, 40 kg P ha^{-1}) et (T6 = 150 kg N ha^{-1}, 50 kg P ha^{-1}). Des différences significatives ($P < 0,05$) ont été observées entre les différents traitements de fertilisation. Ainsi, dans les hautes terres, les meilleurs poids des graines (8,37 g $plant^{-1}$) et rendements en graines (1814,54 kg ha^{-1}) ont été enregistrés pour le traitement T5, tandis que dans les terres moyennes, les meilleurs poids des graines (3,89 g $plant^{-1}$) et rendements en graines (843,97 kg ha^{-1}) ont été enregistrés pour le traitement T6. La biomasse aérienne (32,08 et 18,49 g $plant^{-1}$ respectivement) et la hauteur des plantes (102,34 et 86, cm) les plus élevées ont été enregistrées pour T6 dans l'agroécologie des hautes terres et des terres moyennes. Selon l'analyse de corrélation de Pearson, une corrélation positive significative ($P < 0,001$) a été observée entre la hauteur des plantes, le poids des graines, la biomasse aérienne et le rendement en graines. Globalement, l'agroécologie des hautes terres enregistre une hausse de respectivement 115 %, 18,53 %, 114,95 % et 73,53% du rendement en grains, de la hauteur des plantes, du poids des graines et de la biomasse aérienne, par rapport à l'agroécologie des moyennes terres.

Mots clés : camelina / engrais NP / dega humide / weyna-dega humide / habitat

☆ Contribution to the Topical Issue "Creating new oil & protein crop value chains / Construire de nouvelles filières oléoprotéagineuses"

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1 Introduction

Camelina (*Camelina sativa* L.) is a self-pollinated crop that belongs to the *Brassicaceae* family. It has been cultivated for long time as an important oilseed crop for human food (Zubr, 2003; Russo and Reggiani, 2012). The oil content in the camelina seeds is between 30% and 45%, and the unsaturated fatty acids in the oil could be estimated about 80% of the total fatty acids (Budin *et al.*, 1995). The concentration of oil content varies from variety to variety, and the average oil content is about 42.1 % and the average protein content is 43.3% (Zubr, 2003).

Camelina oil has characteristics that distinguish it from other vegetable oils; above all, it has high α-linolenic acid content, which is an essential fatty acid and is added to foods (Eidhin *et al.*, 2003). The camelina crop fatty acid profile is a bit strange, because it consists lower level of uric acid concentration and comparatively higher level of alpha-linolenic acid (Zubr and Matthäus, 2002). The camelina crop is a biofuel crop having reliable yield (Urbaniak *et al.*, 2008; Krohn and Fripp, 2012; Razeq *et al.*, 2014). Because camelina crop seed has high oil content, which can yield high amount of oil per hectare, it can be processed into high quality renewable energy such as biodiesel as well as diesel and jet fuels, and with this, camelina crop can contribute to economy (Moser, 2010). The oil of camelina can be used as an important source of omega-3 fatty acid because of having low cholesterol properties for the human food (Karvonen *et al.*, 2002). Although the oil of camelina considered as susceptible to lipid oxidation due to the poly-unsaturated fatty acids content, the oil is stable during the storage due to the presence of antioxidants in the seed (Abramovic and Abram, 2005).

Nowadays, the camelina crop production is getting global attention, and many studies have been conducted to check its growth potential and adaptability in different agroecological zones. Zubr (2003) conducted a location-oriented research on different summer varieties in Scandinavia and Northern Europe, and the result indicated the higher impact of climate and soil conditions over the origin of the camelina varieties used. The camelina crop grow better in temperate climatic zones at cool season than warmer season, and beside to being potential crop to support industries through using as raw material for oil production (Karvonen *et al.*, 2002), its oilseed cake can be used as animal feed and soil fertilizer.

Soil preparation, seed depth, seeding rates, and planting methods are the possible factors that affect the camelina grain yield (Berti *et al.*, 2011). Camelina crop can give better yield with low fertilizer input, and it can grow on lands, which have low agricultural values (Putnam *et al.*, 1993). Although overuse of crop residue with improper tillage practices result in reduction of seedling potential, it is assessed that about 5–7 kg seeds ha^{-1} is enough for recommended plant density (Enjalbert and Johnson, 2011). Implementing integrated soil fertility management and appropriate weeding practices are important activities to enhance the camelina crop production. Soil moisture content, before planting soil fertility status, and the type of soil are the major governing factors, which affect the camelina crop cultivation.

In previous researches, it has been explained that with the increase of mineral nitrogen fertilizer input, the total seed yield of camelina is increased, while the oil content in the seeds is reduced (Jiang *et al.*, 2014). In previous studies, phosphorous 15–30 kg ha^{-1}, nitrogen 50–120 kg ha^{-1} and sulfur 10–25 kg ha^{-1} were considered to be adequate (Jiang *et al.*, 2014; Obour *et al.*, 2015) for camelina yield production. In different studies, varying quantities of nitrogen fertilizer application give sufficient yield such as 45–50 kg ha^{-1} (Obour *et al.*, 2015), 120 kg N ha^{-1} (Wysocki *et al.*, 2013) and 185 kg N ha^{-1} (Solis *et al.*, 2013). It has been reported in previous studies that if nitrogen application increased beyond the threshold dose, it may aggravate the camelina loss through lodging effect (Berti *et al.*, 2011; Rathke *et al.*, 2006).

Although the camelina crop is very important for human food oil production (Karvonen *et al.*, 2002), potential agroecological region and recommended rate of NP fertilizer doses in dega and weyna-dega agroecological zones of Ethiopia were not reported. It is imperative to identify the best agroecological zone and the best rate of NP fertilizer dose for potential growth of camelina crop in Ethiopia. Therefore, the current study was conducted in different agroecology and rate of NP fertilizer to see the impact of different agroecological regions on camelina growth and production, and to identify the recommended rate of NP fertilizer dose on midland and highland agroecological zones.

2 Materials and methods

2.1 Description of experimental sites

The current research was conducted in 2021/2022 based on different agroecology at two research sites of Wachemo University, namely, main campus, which is located in Ambicho gode kebele, and Shone site, which is located in Shone town administration, Hadiya Zone, Southern Ethiopia (Fig. 1). According to Hurni (1998), Ethiopian agroecology classification, the altitude (2270–2315 masl) of Wachemo University main campus (Ambicho gode kebele) is categorized under the moist dega agroecology, while the altitude (1989–1995 masl) of Shone research site is categorized under the moist weyna-dega agroecology. The moist dega agroecology (Ambicho gode kebele) is situated at 7°32’0" N to 7°35’30" N latitudes, and 37°51’30" E to 37°55’30" E longitudes, while the moist weyna-dega agroecology (Shone town administration) is situated at 7°7’30" N to 7°9’30" N latitudes, and 37°56’0" E to 37°58’30" E longitudes (Fig. 1). Based on 10 years (2012 to 2021) of meteorological data, the average annual rainfall of moist dega agroecology (main campus research site) is 1286.7 mm, while the moist weyna-dega agroecology (Shone research site) is 1094.5 mm and the average annual minimum and maximum temperatures for the moist dega agroecology are 11.3 °C, and 23.6 °C, respectively, while the mean annual temperature for the moist weyna-dega agroecology is in the range of 18.5 °C to 22 °C. The main rainy season extends from June to September, and the maximum rainfall is received in the months of June, July and August. The major crops grown in moist dega agroecology are enset, wheat, barley, faba bean, pea, while in the moist weyna-dega agroecology (Shone research site) maize, sorghum, teff, tubers, coffee and enset.

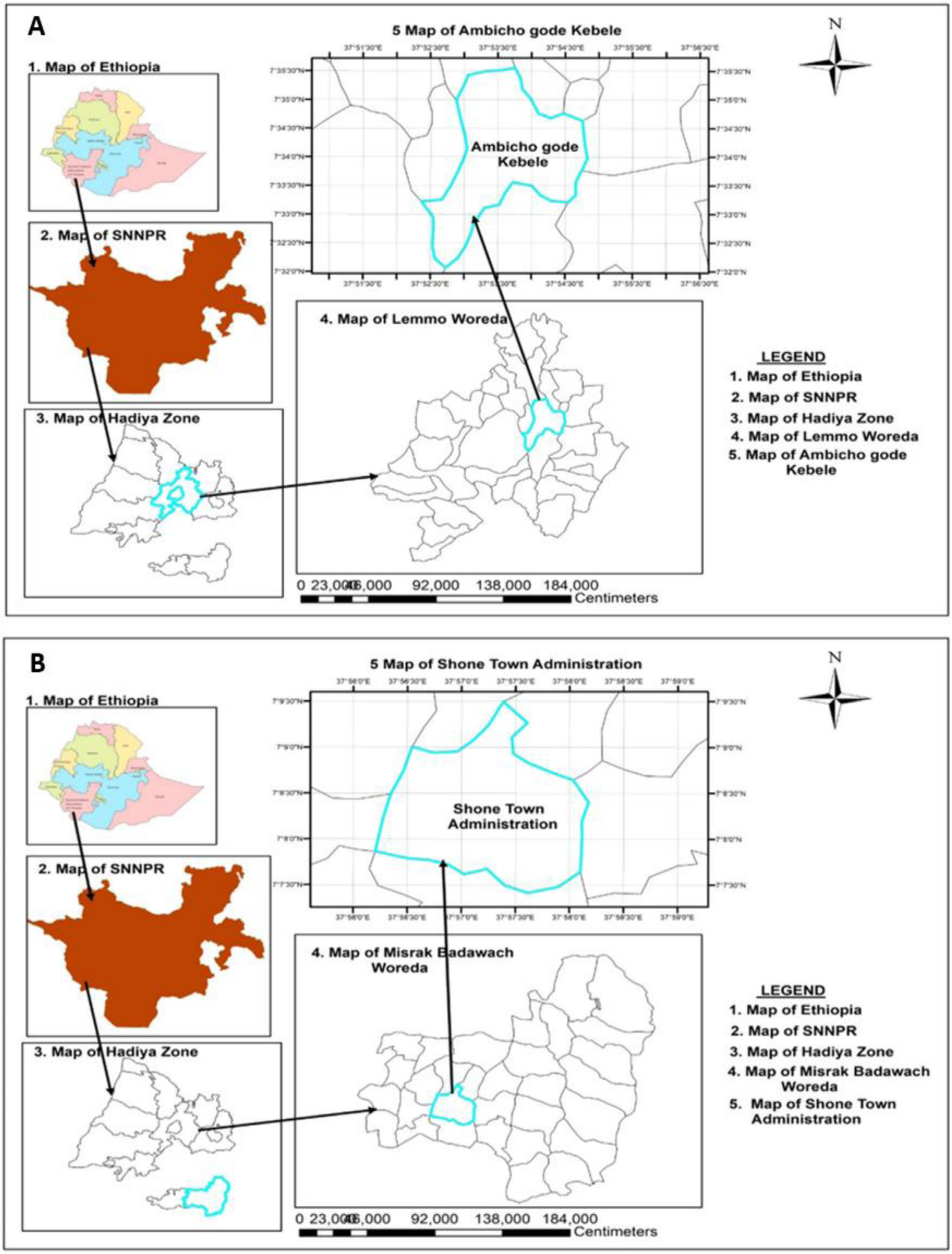

Fig. 1. A: map of Ambicho gode kebele (Wachemo University main campus research site); B: map of Shone town administration (Shone research site).

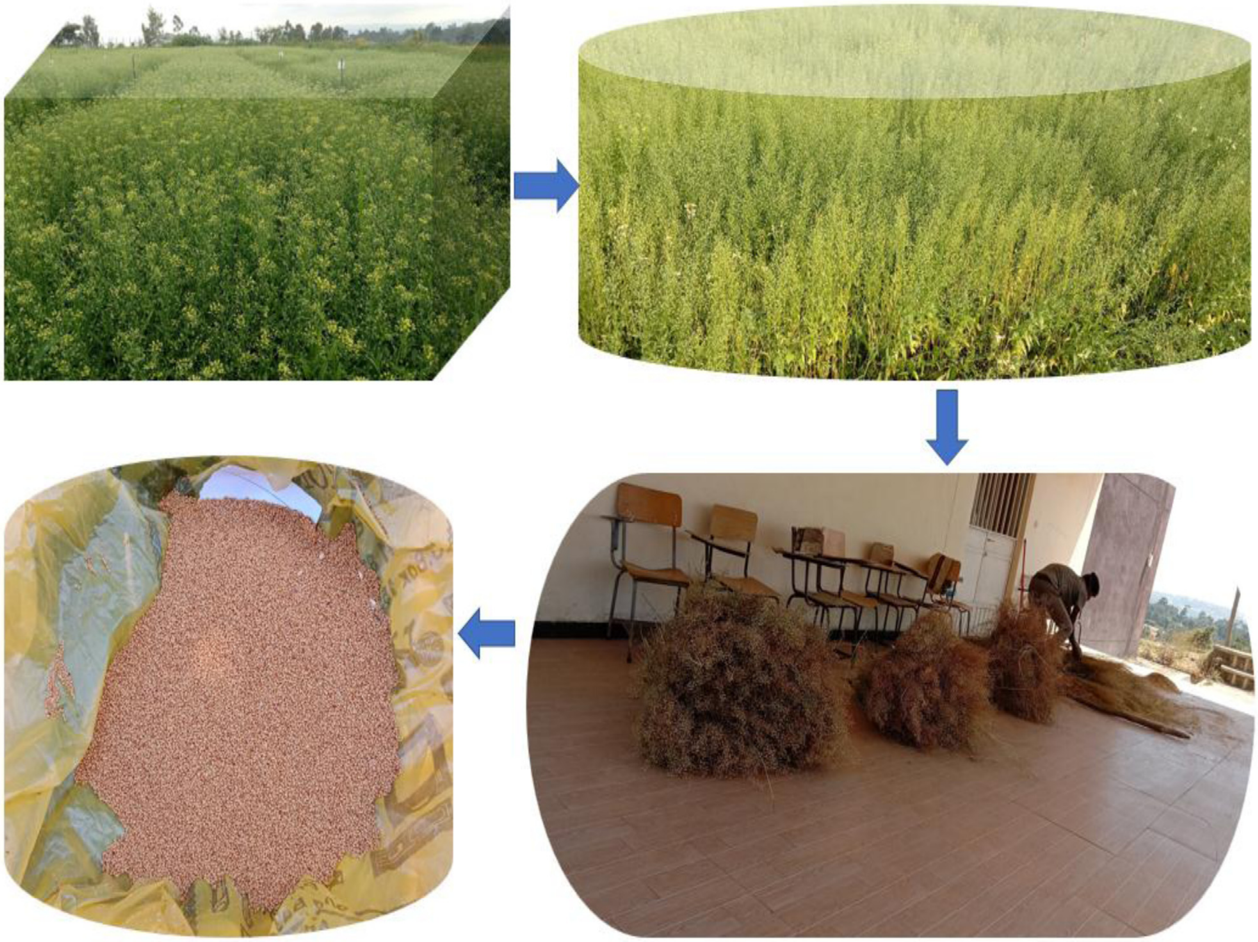

Fig. 2. Camelina crop from flowering stage to yield collection

Table 1. Soil analysis results of highland (moist dega) and midland (moist weyna-dega) agroecological zones.

Agroecology	Av. P (ppm)	pH	Sand (%)	Silt (%)	Clay (%)	Soil textural class name
Highland	5.22	6.74	48	42	10	Loam
Midland	2.09	7.18	60	30	10	Sandy loam

The textural analysis result revealed that the Wachemo University main campus soil (loam type), which is an ideal soil for the crop production.

2.2 Experimental design and treatments

The experimental design for the conducted research was laid in randomized complete block design (RCBD) with three replications. The experimental plot size was 10 m^2. The research was conducted in the rain-fed condition at the agricultural field. The forecrop in each agroecology was wheat. The seed of camelina (*Camelina sativa* L.) Crantz was obtained from the Office of Farm Coordination Center of the Wachemo University, and it was sown based on seeding rate (10 kg/ha) as reported by Manore and Yohannes (2019), and the sowing method was according to the report by Pavlista *et al.* (2011) and Schillinger *et al.* (2012), briefly, seed was broadcasted based on the recommended seed rate per hectare. The seeds were sown in July. The treatments were different rates of NP fertilizer in two different agroecology zones. T1 = (0 kg N ha^{-1}, 0 kg P ha^{-1}), T2 = (30 kg N ha^{-1}, 10 kg P ha^{-1}), T3 = (60 kg N ha^{-1}, 20 kg P ha^{-1}), T4 = (90 kg N ha^{-1}, 30 kg P ha^{-1}), T5 = (120 kg N ha^{-1}, 40 kg P ha^{-1}), T6 = (150 kg N ha^{-1}, 50 kg P ha^{-1}) each treatment was replicated three times in both moist dega agroecology (Wachemo University main campus), and in moist weyna-dega agroecology (Shone research site). The camelina crop from flowering stage to yield collection was explained in Figure 2. Hand weeding practices were conducted on both sites, because using herbicide was not effective (Fig. S1). Soil phosphorus was determined using Olsen's procedure (Olsen *et al.*, 1954). The pH of soil was measured in a 1:2.5 (v/v) soil:water suspension. For the soil texture determination, the samples were taken from both agroecological zones before planting from the top 0–15 cm of the soil, and then the sampled soils were air dried, and then were sieved.

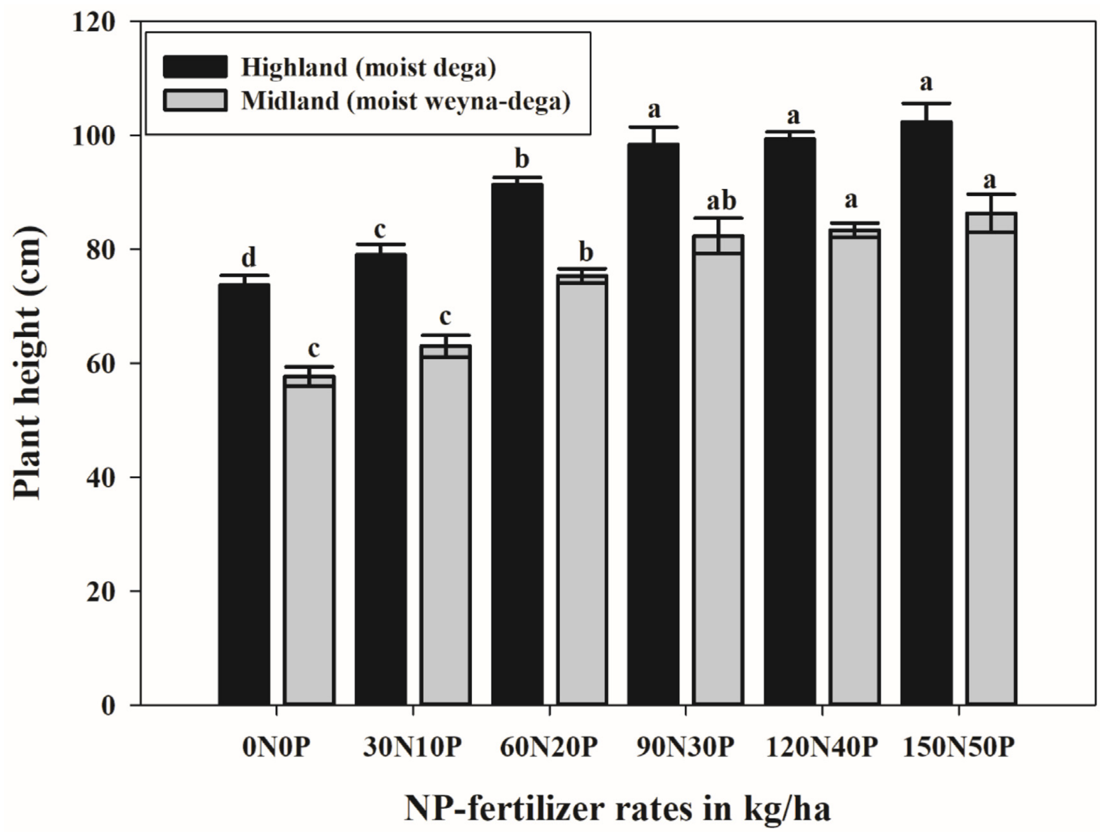

Fig. 3. The camelina plant height in centimeter per plant as influenced by different rates of NP fertilizer and agroecology. 0N0P stands for 0 kg/ha of nitrogen and 0 kg/ha of phosphorous fertilizer, and similarly for 30N10P, 60N20P, 90N30P, 120N40P and 150N50P. The data are the means of three replicates. Differing letters show significant differences in pairwise comparisons (Tukey's test, $P < 0.05$).

2.3 Vegetative and yield response parameters

Plant height (cm) was measured at physiological maturity from the ground level to the tip of four randomly selected plants from each plot (Fig. S2). Dry biomass yield (g/plant) was measured by weighing the sun dry total above ground plant biomass of randomly selected plants per plot. The grain yield (kg/ha) was measured by taking the weight of the grains from the plot area, and then converted to kilogram per hectare. Seed weight (g/plant) was measured by taking the mass of all seeds per plant using a sensitive electronic balance.

2.4 Data analysis

The collected data was subjected to analysis of variance (ANOVA) using General Linear Model (GLM) of Statistical Analysis Software (SAS) version 9.1, and significances among treatment means were determined using LSD at 0.05 probability level. Correlation analysis was done using Pearson's simple correlation coefficient between the parameters.

3 Results and discussion

The soil available phosphorous content and the pH value of the study areas were shown in Table 1, briefly, the soil phosphorus content in the highland agroecological region (Wachemo University main campus) was 5.22 ppm, while in the midland agroecological region (Shone research site) was 2.09 ppm. The soil pH of the highland was 6.74, while the midland was 7.18. The soil textural analysis result of the experimental site indicates that the moist dega agroecology (highland) is the loam type, while the moist weyna-dega agroecology (midland) was sandy loam type (Tab. 1). The type of soils in both agroecology is potential for crop production.

The plant height result showed a significant ($P < 0.05$) difference between the fertilizers rates and agroecology. Accordingly, the highest (102.33 cm) plant height in moist dega agroecology was recorded from 150N50P, while the lowest (73.66 cm) was from 0N0P. Similarly, in the weyna-dega agroecology, the highest (86.33 cm) plant height was recorded from 150N50P, while lowest (57.66 cm) was from 0N0P (Fig. 3). These results agreed with previous study conducted by Nleya *et al.* (2021) on nitrogen fertilizer effect on camelina crop in two locations, and the authors reported that the N rate effects on plant height were significant at both locations, and plant height increased with increase of N rate, and the tallest plants recorded in the highest N rate of 140 kg ha^{-1}. In accordance, Solis *et al.* (2013) reported the positive response of camelina plant height to the increased rate of N fertilizer. From the two agroecologies, moist dega agroecology performed an 18.53 % of plant height increment as compared to weyna-dega agroecology (Fig. 3).

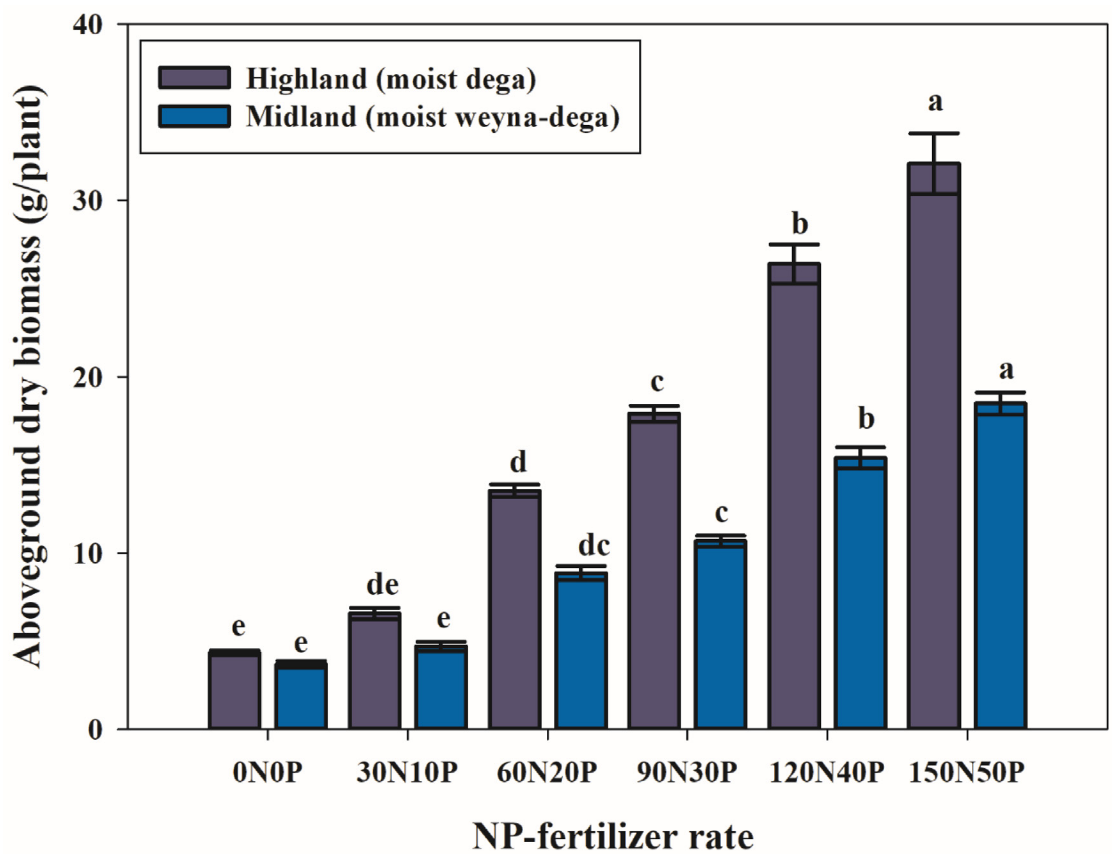

Fig. 4. The camelina aboveground dry biomass in gram per plant as influenced by different rates of NP fertilizer and agroecology. 0N0P stands for 0 kg/ha of nitrogen and 0 kg/ha of phosphorous fertilizer, and similarly for 30N10P, 60N20P, 90N30P, 120N40P and 150N50P. The data are the means of three replicates. Differing letters show significant differences in pairwise comparisons (Tukey's test, $P < 0.05$).

The aboveground dry biomass per plant result showed a significant ($P < 0.05$) difference between the fertilizers rates and agroecology. Accordingly, the highest (32.08 g/plant) aboveground dry biomass in moist dega agroecology was recorded from 150N50P, while the lowest (4.34 g/plant) was from 0N0P. In similar way, in the weyna-dega agroecology, the highest (18.49 g/plant) above ground biomass was from 150N50P, while lowest (3.68 g/plant) was from 0N0P (Fig. 4). This finding could be supported by Lošák *et al.* (2011) who reported the highest straw yield from the highest rate of nitrogen fertilizer. Based on the results, moist dega agroecology (main campus research site) performed 73.53 % increase in aboveground biomass as compared to weyna-dega agroecology (Shone research site). The better growth performance in the moist dega agroecology as compared with weyna-dega agroecology could be the camelina crop need cool climate than warm climate. This idea could be supported by Zhang *et al.* (2021), who reported that camelina is a highly adaptable cool climate crop species. On the other study, Gesch and Cermak (2011) reported that camelina is a winter crop, which needs cool climate.

The result of camelina seed weight (g) per plant showed a significant ($P < 0.05$) difference between the NP fertilizer rates (Fig. 5). Accordingly, in the highland agroecology, the highest seed weight (8.36 g/plant) was recorded from 120N40P while the lowest (0.65 g/plant) was recorded from the 0N0P. On contrary, in the midland agroecology, the highest seed weight (3.89 g/plant) was recorded from 150N50P, while the lowest seed weight (0.303 g/plant) was from control. In this study, the increase in nitrogen rates up to optimum level increases the seed weight. This finding could be supported by Nleya *et al.* (2021) who stated that in three of the four environments, the highest N rate increased seed yield by 30 to 60% compared to the control. The lower seed weight from 150N50P in highland as compared with 120N40P might be due to the high N content caused the lodging effect on the camelina growth. It has been reported in earlier findings that if nitrogen application increased beyond an optimal dose, it may lead to increased lodging (Berti *et al.*, 2011; Rathke *et al.*, 2006). The result suggests that the increase in nitrogen content beyond 120 kg/ha could cause seed weight reduction in soil of Wachemo University main campus, while in the soil of the Shone site, the increase in nitrogen beyond 120 kg/ha increases the seed weight per plant of camelina. From the two agroecology sites, the highland (moist dega) agroecology showed 114.95% seed weight increment as compared moist weyne-dega agroecology.

The result of camelina grain yield (kg/ha) showed a significant ($P < 0.05$) difference between the NP fertilizer rates (Fig. 6). Accordingly, in the highland agroecology, the highest yield (1814.5 kg/ha) was recorded from 120N40P while the lowest (676.6 kg/ha) was recorded from 0N0P. On contrary, in

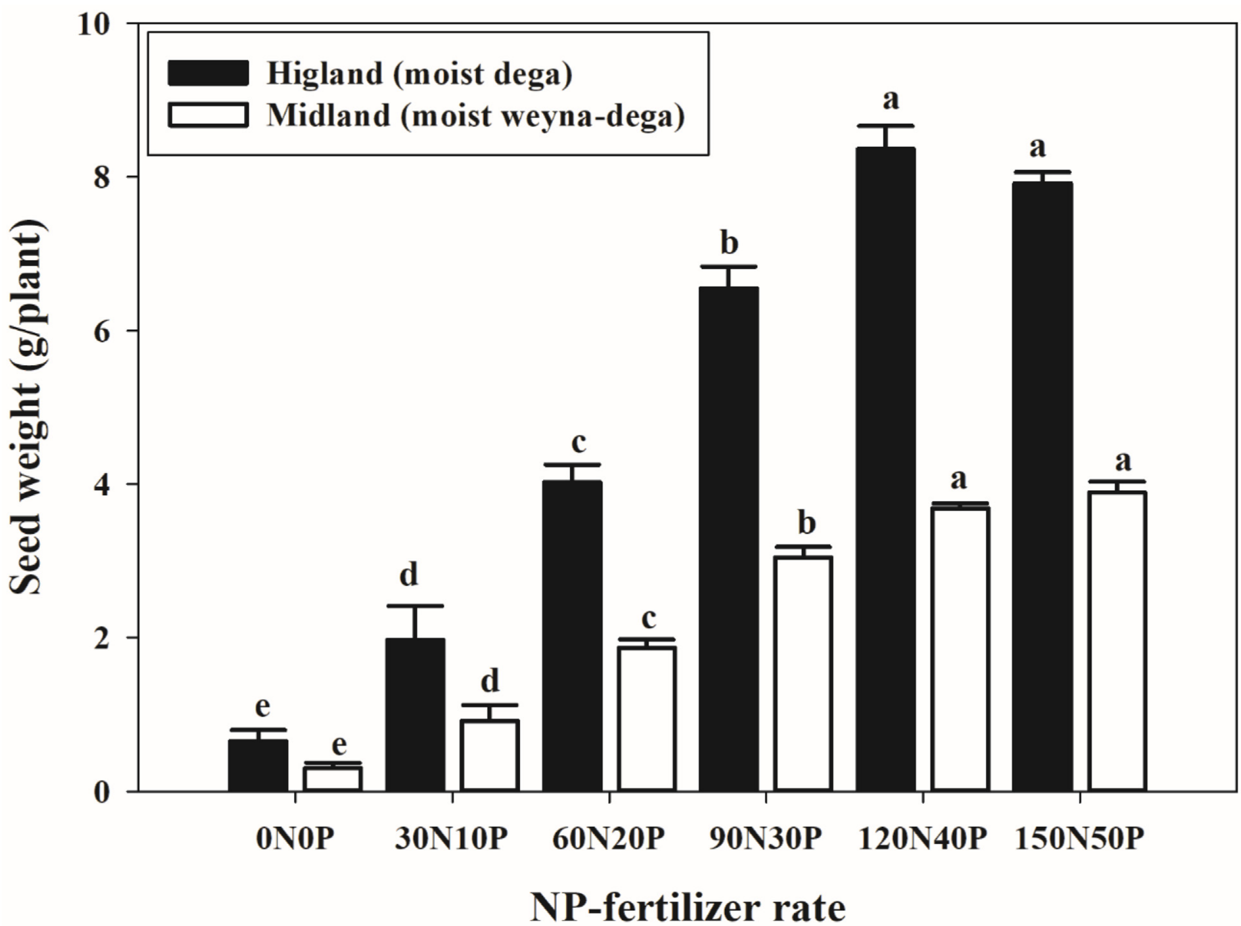

Fig. 5. The camelina seed weight in gram per plant as influenced by different rates of NP fertilizer and agroecology. 0N0P stands for 0 kg/ha of nitrogen and 0 kg/ha of phosphorous fertilizer, and similarly for 30N10P, 60N20P, 90N30P, 120N40P and 150N50P. The data are the means of three replicates. Differing letters show significant differences in pairwise comparisons (Tukey's test, $P < 0.05$).

the midland agroecology, the highest yield (843.9 kg/ha) was recorded from 150N50P. The increase in yield as increase in nitrogen fertilizer application can be supported with the previous reports of Wysocki *et al.* (2013) and Solis *et al.* (2013), who stated that varying quantities of nitrogen 120 kg N ha^{-1} and 185 kg N ha^{-1}, respectively give sufficient yield in camelina. Similarly, Malhi *et al.* (2014) conducted an experiment on different rates of N-fertilizer, and reported the highest camelina grain yield from 170 kg N/ha, and stated that camelina responded fairly to high rates of applied N. In the current study, the lower yield from 150N50P in highland as compared with 120N40P might be due to the high N content causing the lodging effect on the camelina growth. This idea could be supported by Strasil and Skala (1995) who stated that higher N doses on fertile soils can cause partial lodging of camelina crop. The current results suggest that the increase in nitrogen fertilizer rate beyond 120 kg/ha could cause yield reduction in soil of Wachemo University main campus, while in the soil of Shone site, the increase in nitrogen beyond 120 kg/ha can increase the yield of camelina. From the two agroecological sites, the highland (moist dega) agroecology showed 114.95% yield increase as compared to moist weyna-dega agroecology.

The Pearson's correlation analysis results between the plant height (PH), aboveground dry biomass per plant (AGB), seed weight per plant (SEW) and grain yield (GY) in both highland and midland agroecological regions showed strong positive significant ($P < 0.001$) correlation between them (Tab. 2).

4 Conclusions

The experiment on effect of different agroecology and rate of NP fertilizer on camelina crop growth was conducted to identify the suitable agroecology and NP fertilizer dose for the potential crop production. According to the results obtained from highland (moist dega) and midland (moist weyna-dega) agroecologies, the camelina crop performed better growth and yield production in highland agroecology as compared to midland. Accordingly, the moist dega agroecology showed 18.53%, 73.53% 115% and 114.95% increase in plant height, aboveground biomass, grain yield, and seed weight, respectively as compared to midland agroecology. The increase in NP fertilizer applications increased the camelina growth and yield. Although for most growth parameters, the highest value

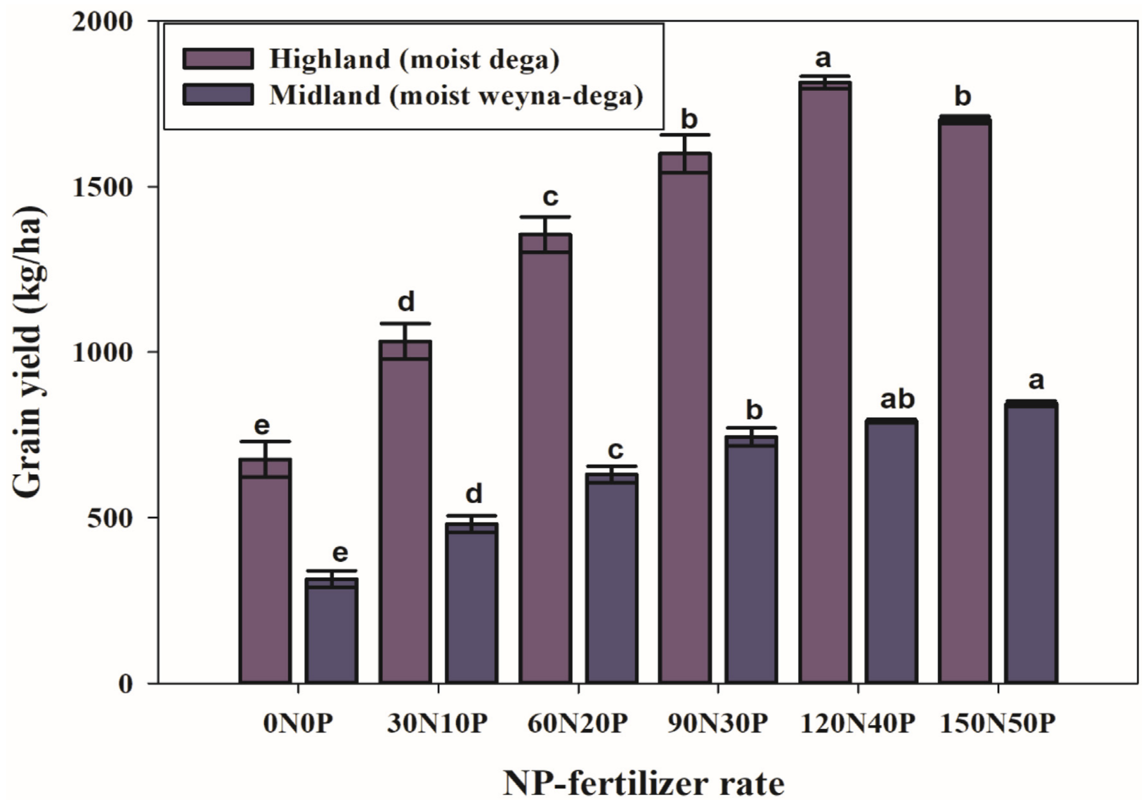

Fig. 6. The camelina grain yield per ha as influenced by different rates of NP fertilizer and agroecology. 0N0P stands for 0 kg/ha of nitrogen and 0 kg/ha of phosphorous fertilizer, and similarly for 30N10P, 60N20P, 90N30P, 120N40P and 150N50P. The data are the means of three replicates. Differing letters show significant differences in pairwise comparisons (Tukey's test, $P < 0.05$).

Table 2. Pearson's correlation coefficient among seed weight per plant (SEW), aboveground dry biomass per plant (AGB), plant height (PH) and grain yield (GY).

	SEW	AGB	PH	GY
SEW	1			
AGB	HL = 0.9457*** ML = 0.9251***	1		
PH	HL = 0.9446*** ML = 0.9227***	HL = 0.8988*** ML = 0.8648***	1	
GY	HL = 0.9682*** ML = 0.9435***	HL = 0.8982*** ML = 0.8646***	HL = 0.9602*** ML = 0.9386***	1

HL = highland (moist dega) and ML = midland (moist weyna-dega) agroecological zones. Correlation is significant at $P < 0.05$ level (*), $P < 0.01$ level (**) or at $P < 0.001$ level (***).

recorded from 150 kg N with 50 kg P application, for the grain yield per hectare and seed weight per plant, the highest values were recorded from 120 kg N and 40 kg P in the highland agroecology. This might be due to high N fertilizer rate causing lodging effects in highland agroecology. In general, the overall result showed that camelina crop can produce a potential yield in highland agroecology with fertilizer rate 120 kg N and 40 kg P.

Supplementary Material

Fig. S1. Hand weeding practices at Shone and Wachemo University research sites.
Fig. S2. Camelina crop morphology at flowering stage.

The Supplementary Material is available at https://www.ocl-journal.org//10.1051/ocl/2023001/olm.

Acknowledgments. The authors fully acknowledge Wachemo University for funding the research budget and providing the research sites for the experiments.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to this article.

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Cite this article as: Sido MY, Chernet M, Ayele W, Sinore T, Tagesse B. 2023. Response of oil producing camelina (*Camelina sativa* L.) crop to different agroecology and rate of NP fertilization. *OCL* 30: 3.