Article

Grazing and Cutting under Different Nitrogen Rates, Application Methods and Planting Density Strongly Influence Qualitative Traits and Yield of Canola Crop

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Abstract: Canola crop has the potential for both seeds and grazing. Optimal planting density, time of nitrogen (N) fertilizer application and rates are the major aspects for successful qualitative traits and canola yield formation. In this content, optimization of planting density, N levels and its time of application in dual purpose canola are needed. This study was carried out in RCB design with split pot arrangement having three repeats during winter 2012–2013 and 2013–2014. The study evaluated N levels (120 and 80 kg N ha^{-1}), cutting treatment, N application timings and planting density (20 and 40 plants m^{-2}) effects on qualitative traits and yield of canola. No-cut treatment had 7.02%, 2.46%, and 4.26% higher, glucosinolates, oil, and protein content with 31.3% and 30.5% higher biological and grain yield respectively, compared with grazed canola. Compared with no-cut canola, grazed canola resulted in 7.74% of higher erucic acid. Further, application of N at 120 kg N ha^{-1} had 8.81%, 5.52%, and 6.06% higher glucosinolates, percent protein, and seed yield, respectively than 80 kg N ha^{-1}. In-addition, the application of N into two splits was most beneficial than the rest application timings. Cutting had 15% reduction in grain yield of canola and fetched additional income of 143.6 USD compared with no-cut. Grazing resulted in a 23% reduction in grain yield while had additional income of 117.7 USD from fodder yield. Conclusively, the application of N in two splits at 120 kg N ha^{-1} combined with 20 plants m^{-2} is a promising strategy to achieve good qualitative attributes and canola yield under dual purpose system.

1. Introduction

The domestic production can only meet 29% of the total edible oil requirements of Pakistan and the remaining 71% was mad through imports [1]. Like other developing countries, Pakistan is also deficit in edible oil production. According to a study conducted the consumer's demand has steadily increased from 0.3 million tons to 2.764 tons during the last two and half decades. The average yield of canola in Pakistan is 839 kg ha^{-1} [2], which is very low compared with other agriculturally advanced countries. The European countries have a yield level of 3500 kg ha^{-1}; Canada 3200 kg ha^{-1}; and Australia 2000 kg ha^{-1} for canola crop [3]. To cut down these gaps concrete efforts are needed to increase its local production. Canola is an improved form of conventional rape seed variety developed through genetic engineering having erucic acid less than 2% and 30 μmolg^{-1} glucosinolates, which are considered the safe limits for health [4]. As compared to other oil crops, it contains less amount of cholesterol [3]. Seed oil concentration was inversely proportional to seed protein concentration in mustard and canola genotypes. Increase in seed yield increased the oil concentration, but decreased the protein concentration [5].

Optimum amount of nutrients supply at proper time to any crop is important [6]. Canola crop requires a higher amount of nutrients, and available nitrogen (N) compared with cereals [7]. Split application of N fertilizer has become more popular in terms of high nitrogen use efficiency. An appropriate rate and timing of N fertilizer application is one of the most important aspects of successful canola production [3]. Canola yield is strongly correlated with biotic and abiotic factors; one of the factors that availability of nutrients especially N is the key driver for improving root growth, leaf photosynthetic rate, biomass production, and yield [8]. N fertilizer boosts yield improving thousand seed weights, seeds pod^{-1}, and pod number plant^{-1} [9]. Dual purpose cropping is the use of crops for fodder purpose at vegetative stage grazed by animals. The regrowth of plants after cutting or grazing strongly relies on the regenerative ability of the species. After being in stress condition, soon after grazing crops N fertilization is needed for growth improvement, thus N fertilizer selection is a good choice for growth improvement. Increasing N level from normal or recommended dozes boosts the overall plant health and seed production [9]. Considering DP canola, N fertilizer might be increased for better re-growth or regeneration of canola. Moreover, N is the most volatile and due to high losses, N efficiency becomes lesser and thereby affects plant normal functioning [10]. Winter or long-season spring canola with proper N rates can be sown to produce high-quality forage for grazing or fodder for cut and carry and recover from grazing to produce a high grain yield (4 t/ha) with good oil content (47%) [11]. Canola crop has the potential to produce grains and to graze. Although, canola crop is good for forage. Canola grazing is only one of the assortments of choice to the farmers to perk up farm economics and productivity.

However, oil quality is also important, and contains less amount of cholesterol, which is good for human health. Studies regarding N rate, timing, and planting density under dual purpose canola production are lacking. The objectives of this study were to explore canola qualitative and yield attributes to different N rate, application, and planting density under dual purpose canola technology. This study also explores the quantitative relationship among N level, application time and planting density for dual purpose use of canola. Furthermore, the combination of all above discussed factors will make an understanding of the effect of grazing on the yield and quality of canola crop and even development of commercial grazing practices. The tested hypothesis was that N rate, time of application, and planting density would improve canola qualitative traits and yield under dual purpose technology.

2. Materials and Methods

2.1. Experimental Site

The present study was conducted at New Developmental Farm of Agricultural University Peshawar during Rabi 2012–2013. The research farm is located about 300 m above the sea level, while the site has 34° N latitude and 72° E longitude. The soil of the site was clay loamy having pH values ranges between 7.0–7.5. Temperature (°C) and rainfall (mm) during the crop growing season have been shown in Figure 1. Weather data were collected from the meteorological station located near the experimental site.
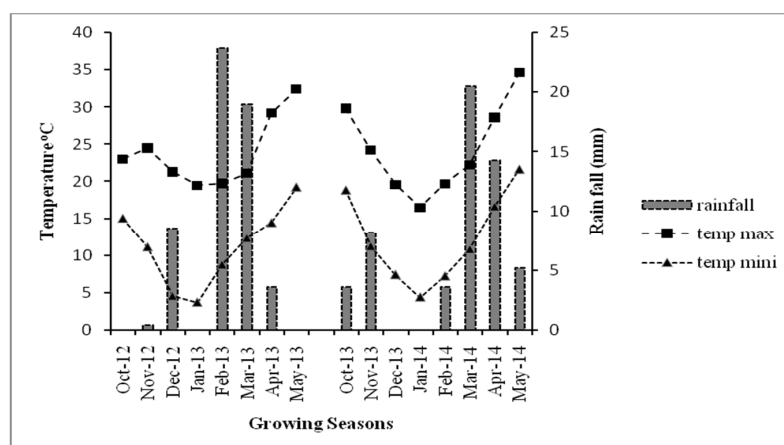

Figure 1. Annual rainfall, maximum and minimum temperature of the experimental site for 2012–2013 and 2013–2014.

2.2. Treatments and Methods

The experiment contained two levels (80 and 120 kg ha^{-1}) of nitrogen levels (NL), cuttings (C; (cut, no cut and grazing), application timing (NT; (a) full application at sowing, (b) half dose of N both at sowing and start of rosette stage, (c) one third dose of N each at sowing, start of rosette stage and soon after cut at late rosette stage (60 days after sowing) and plant density (PD: 20 and 40 plants m^{-2}) (Table 1). In 2012–2014, the experiment was conducted in RCB design with split plot arrangement having three replications. Cutting and N levels (urea as a source of nitrogen was applied as top dressed) were assigned to the main plot while N application timings and planting densities were allotted to sub-plot. Cutting and grazing were done 60 days after sowing. Cutting was done manually by cutting the crop at about 10 cm above the ground. However, grazing was done through sheep for predetermined time.

Table 1. The detailed presentation of experimental treatments.

| Main Plot Factors	Treatment Levels	Sub Plot Factors	Treatment Levels
Cuttings (C)	No-cut (C1)	Nitrogen application timings (NT)	(1) full application at sowing (NT$_1$)
	Cut (C2)		(2) half dose of N both at sowing and start of rosette stage (NT$_2$)
	Grazing (C3)		(3) one third dose of N each at sowing, start of rosette stage and soon after cut at late rosette stage (60 days after sowing (NT$_3$)
Nitrogen Levels (NL)	80 kg ha^{-1} (NL$_1$) 120 kg ha^{-1} (NL$_2$)	Planting density (PD)	20 plants m^{-2} (PD$_1$) 40 plants m^{-2} (PD$_2$)

2.3. Field Preparation and Cultural Practices

Cultivar Abasin-95 was sown with a uniform seed rate of 8 kg ha^{-1}. Row to row distance of 50 cm was maintained with a subplot size of 10.5 m^2, having 7 rows, and 3 m long. Before sowing, a fine

seedbed was prepared by ploughing the field with cultivator followed by rotavator. A basal dose of phosphorus at 60 kg ha^{-1} was applied in the form of single super phosphate. Nitrogenous fertilizer was applied in the form of urea. Weeds were controlled manually by hoeing, when the crop reached 6–8 cm height. The field was harvested on 10 April each year. All cultural practices were carried out uniformly in all plots.

2.4. Grazing Management

Sheep stock was arranged for grazing canola from nearby village. The sheep were allowed to graze a normal canola field about five days before the treatment grazing to acclimatize them to canola/brassica consumption. The sheep were controlled with the help of fences from going to other treatment plots. Animals for grazing were allowed in noon time because of much frost in morning time during grazing period in the month of December in both years.
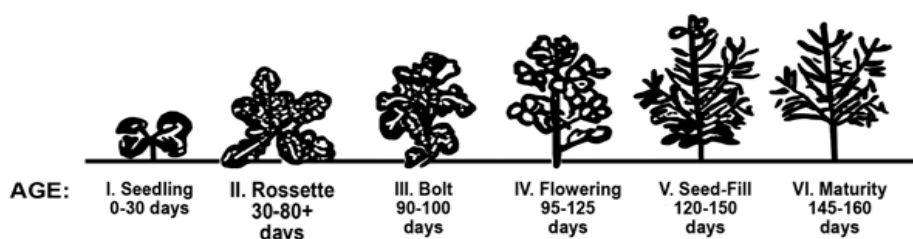
Canola growth stages.

2.5. Observations

2.5.1. Quality Attributes of Canola

Protein, percent oil content, erucic acid, and glucosinolates were determined by collecting randomly seed samples in each plot and were analyzed by Full Option Science System (FOSS) Routine Near Measurement System (35RP-3752F) TR-3657-C Model 6500, at oilseed laboratory, Nuclear Institute for Food and Agriculture, Peshawar (NIFA). Near infrared reflectance (NIR) spectroscopy is a quick and whole seed analyzing method, which does not require any sample preparation or chemicals [12].

2.5.2. Canola Yield

Biomass yield was determined by harvesting of four central rows, dried and weighted. While in order to determine grain yield, bundles from the same central four rows were threshed, seeds were weighed and the data were converted to kg ha^{-1} [13].

2.5.3. Statistical Analysis

The data were statistically analyzed over years using ANOVA techniques appropriate for RCB design with split plot arrangement using SPSS software (SPSS Inc., Chicago, IL, USA). Means were compared using LSD test at 0.05 level of probability, when the *F*-values were significant [14].

3. Results

3.1. Treatments Interactions

The significance ANOVA for main factors and interaction is presented in Table 2. The C × NL significantly affected on Glucosinolates, while the rest of treatments interaction were not significant. Oil content were significantly affected by the C × NL, C × NT, and NT×PD treatments. Protein content was not significant throughout the treatments' interactions. Eurcic acid showed significant differences on C × PD treatment, while biological yield was significant on C × NL, and NT × NL, and grain yield was on C × NT, and NT × PD treatments.

Table 2. Mean square table for crop yield, qualitative attributes, glucosinulates, and erucic acid for the years 2012–14.

SOV	Grain Yield	Biological Yield	Oil Content	Protein Content	Glucosinulates Content	Eurcic Acid
Year	134 ns	7.397 *	1598.49 *	10,560.2	799.26 *	346.56 *
Cuttings (C)	1,482,015 *	1.383 *	18.93 *	27.7 ns	330.24 *	115.59 *
N-levels (NL)	204,857 *	5,140,844 ns	243.63 *	135.9	1547.22 *	22.556 ns
Planting densities (PD)	45,182 ns	4,630,281 *	18.84 *	1.2 ns	1.23 ns	6.476 ns
Nitrogen timings (NT)	30,938 ns	6,378,573 *	23.12 *	1.9 ns	6.18 ns	14.529 ns
C × NL	ns	*	*	ns	*	ns
C × NT	*	ns	*	ns	ns	*
C × PD	ns	ns	ns	ns	ns	ns
NL × PD	ns	ns	ns	ns	ns	ns
NT × NL	ns	*	ns	ns	ns	ns
NT × PD	*	ns	*	ns	ns	*
C × NT × NL	ns	ns	ns	ns	ns	ns
C × NT × PD	ns	ns	ns	ns	ns	ns
NT × NL × PD	ns	ns	ns	ns	ns	ns
C × NL × NT × PD	ns	ns	ns	ns	ns	ns

Note: ns = non-significant, * = Significant at 5% level of probability.

3.2. Crop Yield

The significance ANOVA for main factors is presented in Table 2. Canola biomass yield was significantly affected by C, PD, and year, whereas NL and NT did not affect biomass yield (Table 3). C_3 and C_2 decreased biological yield by 11.74% and 31.2% compared with that of C_1. Plants grown at PD_2 had 5.3% higher biological yield than PD_1. The C, NL, and NT significantly influenced grain yield of canola, whereas the effect of planting density and year remained unaffected on grain yield (Table 4). The interactions among C × NT and NT × PD were significant. Higher grain yield was produced in C_1 plots, followed by C_2 plots, whereas lower grain yield resulted in C_3 plots. Grain yield was higher when N was applied at NT_2 as compared to NT_3.

Table 3. Biomass yield (kg ha^{-1}) of canola under cutting treatments, nitrogen levels and application timings under different planting densities.

Variables	2012–2013	2013–2014	Two Years Average
Cutting treatments (C)			
C_1	9695 a	9353 a	9524a
C_2	7272 b	9774 a	8523 b
C_3	6080 c	8432 b	7256 c
LSD $_{(0.05)}$	598	631	407
Nitrogen levels (NL)			
NL_1	8099	8794 b	8446
NL_2	7932	9578 a	8755
Significance level	ns	*	ns
N application timings (NT)			
NT_1	7974 ab	9023	8496
NT_2	7700 b	9428	8564
NT_3	8372 a	9107	8739
LSD $_{(0.05)}$	500	506	352
Planting density (PD)			
PD_1	7785 b	8584 b	8454 b
PD_2	8264 a	9787 a	8747 a
Significance level	*	*	*
Year (*)	8016 b	9186 a	

Note: Cuttings (C): no-cut (C_1), cutting (C_2), grazing (C_3); Nitrogen levels (NL): 80 kg ha^{-1}(NL_1), 120 kg ha^{-1} (NL_2); Nitrogen timings: Full application at sowing (NT_1), half dose of N both at sowing and start of rosette stage (NT_2), one third dose of N each at sowing, start of rosette stage and soon after cut at late rosette stage (60 days after sowing (NT_3); Planting density (PD): 20 plants m^{-2} (PD_1), 40 plants m^{-2} (PD_2). Means of the same category followed by different letters are significantly different at 5 % level of probability using LSD $_{(0.05)}$ test. ns = non-significant, * = Significant at 5% level of probability.

Table 4. Grain yield (kg ha^{-1}) of canola under cutting treatments, nitrogen levels and application timings under different planting densities.

Variables	2012–2013	2013–2014	Two Years Average
Cutting treatments (C)			
C_1	1291 a	1128 a	1210 a
C_2	983 b	1068 b	1025 b
C_3	886 c	968 c	927 c
LSD $_{(0.05)}$	72.0	54.1	42.2
Nitrogen levels (NL)			
NL_1	1022 b	1024 b	1023 b
NL_2	1084 a	1086 a	1085 a
Significance level	*	*	*
N application timings (NT)			
NT_1	1021 b	1054 a	1045 ab
NT_2	1029 b	1058 a	1078 a
NT_3	1109 a	1052 a	1039 b
LSD $_{(0.05)}$	42.5	64.6	38.3
Planting density (PD)			
PD_1	1066	1057	1039
PD_2	1044	1053	1068
Significance level	ns	ns	ns
Year (ns)	1053	1055	

Note: Cuttings (C): no-cut (C_1), cutting (C_2), grazing (C_3); Nitrogen levels (NL): 80 kg ha^{-1}(NL_1), 120 kg ha^{-1} (NL_2); Nitrogen timings: Full application at sowing (NT_1), half dose of N both at sowing and start of rosette stage (NT_2), one third dose of N each at sowing, start of rosette stage and soon after cut at late rosette stage (60 days after sowing (NT_3); Planting density (PD): 20 plants m^{-2} (PD_1), 40 plants m^{-2} (PD_2). Means of the same category followed by different letters are significantly different at 5 % level of probability using LSD $_{(0.05)}$ test. ns = non-significant, * = Significant at 5% level of probability.

3.3. Quality Parameters of Canola

3.3.1. Oil Content (%) and Protein Content (%)

Cuttings, PD, NL, NT, and years significantly affected oil content of canola crop (Table 5). A 1.4% higher oil content was resulted in C_1 followed by C_2. The C_3 plots substantially reduced oil content. Application of NL1 had 5.07% of higher oil content compared with NL_2. Oil content was higher NT_2 followed by NT_3 and NT_1. Between planting densities, plants under PD_2 had higher oil content compared with PD_1. The C × NL interaction showed an obvious reduction in oil content for C_2 and C_3 plots under NL_2, whereas the oil content of all cutting treatments remained unchanged under NL_1 application (Figure 2A). Interaction between C × NT showed that canola oil content decreased in C_3 plots at NT_2 than C_1 and C_2. On other hand, oil content of all cutting treatments remained unchanged under three equal splits application of N (Figure 2B). Interaction between NT and PD indicated that oil content was reduced for PD_1 with sole N at sowing than two or three splits and planting densities (Figure 2C). Cuttings, NL and years had remarkedly effects on grain protein content of canola seeds while the effects of NT and PD were insignificant (Table 5). Higher protein content was noted for cut plots which were statistically at par with C_3 plots, while C_1 plots had lower crude protein content in canola seed. The application of NL_2 had 5.5% higher crude protein content compared with that of NL_1 (Table 6).

Table 5. Canola oil content (%) in response to cutting treatments, nitrogen levels and application timings under varying planting densities.

Variables	2012–2013	2013–2014	Two Years Average
Cutting treatments (C)			
C_1	40.78 a	45.95 a	43.37 a
C_2	40.03 b	45.51 ab	42.77 b
C_3	39.51 b	45.18 b	42.35 c
LSD $_{(0.05)}$	0.67	0.59	0.42
Nitrogen levels (NL)			
NL_1	41.13 a	46.66 a	43.89 a
NL_2	39.09 b	44.44 b	41.77 b
Significance level	*	*	*
N application timings (NT)			
NT_1	39.81 b	45.33 ab	42.26 b
NT_2	39.77 b	45.09 b	43.39 a
NT_3	40.74 a	46.22 a	42.83 ab
LSD $_{(0.05)}$	0.75	0.90	0.58
Planting density (PD)			
PD_1	40.00	45.35	42.53 b
PD_2	40.21	45.76	43.12 a
Significance level	*	ns	*
Year (*)	40.11 b	45.55 a	

Note: Cuttings (C): no-cut (C_1), cutting (C_2), grazing (C_3); Nitrogen levels (NL): 80 kg ha^{-1}(NL_1), 120 kg ha^{-1} (NL_2); Nitrogen timings: Full application at sowing (NT_1), half dose of N both at sowing and start of rosette stage (NT_2), one third dose of N each at sowing, start of rosette stage and soon after cut at late rosette stage (60 days after sowing (NT_3); Planting density (PD): 20 plants m^{-2} (PD_1), 40 plants m^{-2} (PD_2). Means of the same category followed by different letters are significantly different at 5 % level of probability using LSD $_{(0.05)}$ test. ns = non-significant, * = Significant at 5% level of probability.

Table 6. Canola protein content (%) in response to cutting treatments, nitrogen levels and application timings under varying planting densities.

Variables	2012–2013	2013–2014	Two Years Average
Cutting treatments (C)			
C_1	36.26	21.56 b	28.91 b
C_2	37.25	23.00 a	30.14 a
C_3	36.19	23.21 a	29.70 ab
LSD $_{(0.05)}$	2.01	1.07	1.06
Nitrogen levels (NL)			
NL_1	35.90	21.69 b	28.79 b
NL_2	37.26	23.50 a	30.38 a
Significance level	ns	*	*
N application timings (NT)			
NT_1	35.90 b	22.93	29.44
NT_2	36.45 ab	22.57	29.76
NT_3	37.37 a	22.58	29.55
LSD $_{(0.05)}$	1.42	0.83	0.81
Planting density (PD)			
PD_1	36.24	23.03 a	29.5
PD_2	36.92	22.16 b	29.66
Significance level	*	*	ns
Year (*)	22.59 b	36.58 a	

Note: Cuttings (C): no-cut (C_1), cutting (C_2), grazing (C_3); Nitrogen levels (NL): 80 kg ha^{-1}(NL_1), 120 kg ha^{-1} (NL_2); Nitrogen timings: Full application at sowing (NT_1), half dose of N both at sowing and start of rosette stage (NT_2), one third dose of N each at sowing, start of rosette stage and soon after cut at late rosette stage (60 days after sowing (NT_3); Planting density (PD): 20 plants m^{-2} (PD_1), 40 plants m^{-2} (PD_2). Means of the same category followed by different letters are significantly different at 5 % level of probability using LSD $_{(0.05)}$ test. ns = non-significant, * = Significant at 5% level of probability.
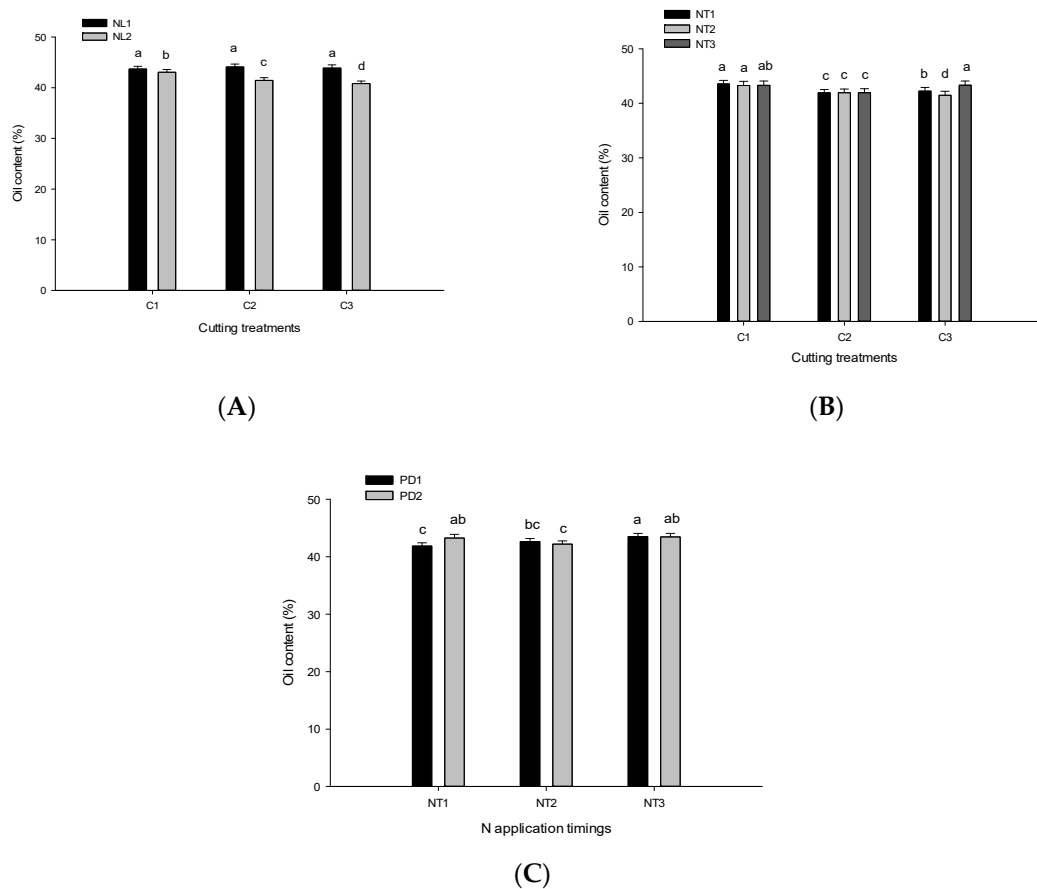
(A)

(B)

(C)

Figure 2. The interactive effects of nitrogen levels and cutting treatments (**A**), nitrogen application timings and cutting treatments (**B**), and nitrogen application timings and planting densities (**C**) for oil content. Vertical bars represent Standard Error. Note: Cuttings (C): no-cut (C_1), cutting (C_2), grazing (C_3); Nitrogen levels (NL): 80 kg ha^{-1}(NL_1), 120 kg ha^{-1} (NL_2); Nitrogen timings: Full application at sowing (NT_1), half dose of N both at sowing and start of rosette stage (NT_2), one third dose of N each at sowing, start of rosette stage and soon after cut at late rosette stage (60 days after sowing (NT_3); Planting density (PD): 20 plants m^{-2} (PD_1), 40 plants m^{-2} (PD_2).
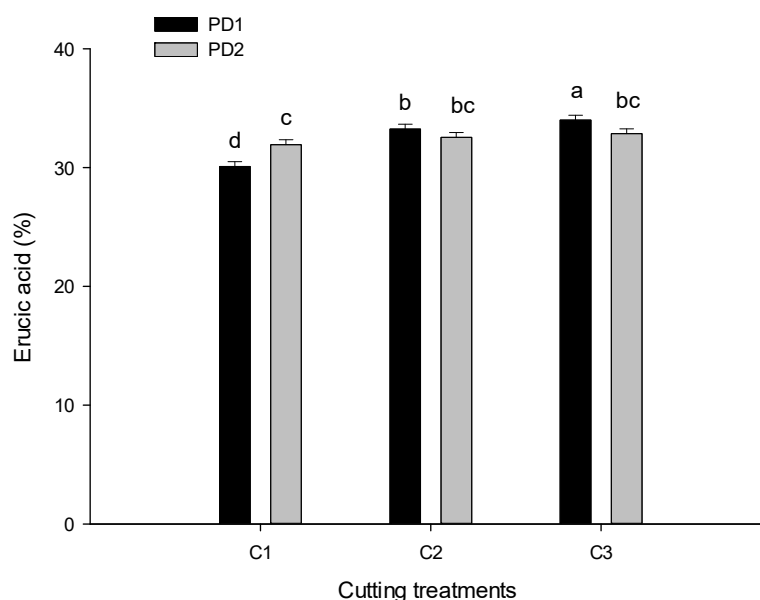
3.3.2. Erucic acid Content (%)

Canola erucic acid content was significantly influenced by C and NT, while the effect of year, NL and PD was non-significant (Table 7). Erucic acid content was 7.7% higher in C_3 than other cutting treatments. Similarly, NT_1 had higher erucic acid content than NT_2 or NT_3. In addition, in the first year the content was 8.07% higher than 2nd year of the study. However, significant C $\times$ PD interaction revealed that erucic acid content increased with imposition of C_2 and C_3 than C_1 under PD_1. No or least variation in erucic acid content in all cutting treatments was noted under PD_2 treatment (Figure 3).

Table 7. Erucic acid (%) canola as affected by cutting treatments, nitrogen levels and application timings under varying planting densities.

Variables	2012–2013	2013–2014	Two Years Average
Cutting treatments (C)			
C_1	32.3 b	31.2 b	31.0 b
C_2	34.1 ab	33.1 ab	32.9 a
C_3	34.7 a	33.6 a	33.4 a
LSD $_{(0.05)}$	1.94	1.91	1.26
Nitrogen levels (NL)			
NL_1	33.4	32.3	32.1
NL_2	34.1	32.9	32.8
Significance level	ns	ns	ns
N application timings (NT)			
NT_1	33.9	32.8	32.9 a
NT_2	33.9	32.8	32.0 b
NT_3	33.3	32.1	32.4 ab
LSD $_{(0.05)}$	ns	ns	0.805
Planting density (PD)			
PD_1	33.7	32.6	32.3
PD_2	33.7	32.5	32.6
Significance level	ns	ns	ns
Year (*)	33.72 a	31.2 b	

Note: Cuttings (C): no-cut (C_1), cutting (C_2), grazing (C_3); Nitrogen levels (NL) 80 kg ha^{-1}(NL_1), 120 kg ha^{-1} (NL_2); Nitrogen timings: Full application at sowing (NT_1), half dose of N both at sowing and start of rosette stage (NT_2), one third dose of N each at sowing, start of rosette stage and soon after cut at late rosette stage (60 days after sowing (NT_3); Planting density (PD): 20 plants m^{-2} (PD_1), 40 plants m^{-2} (PD_2). Means of the same category followed by different letters are significantly different at 5% level of probability using LSD $_{(0.05)}$ test. ns = non-significant, * = Significant at 5% level of probability.

Figure 3. The interactive effect of planting density and cutting treatments of Erucic acid (%) for canola seed. Vertical bars represent Standard Error. Note: Cuttings (C): no-cut (C_1), cutting (C_2), grazing (C_3); Planting density (PD): 20 plants m^{-2} (PD_1), 40 plants m^{-2} (PD_2).

3.3.3. Glucosinolates Concentration

Canola glucosinolates concentration was substantially impacted by C, NL and year, while the effect of NT and, PD and year was not significant (Table 8). Glucosinolates content was 4% higher

in C_1 followed by C_2, while C_3 resulted in lower content of glucosinolates. Similarly, glucosinolates concentration increased with the increased of N level from 80 to 120 kg ha^{-1}. Glucosinolates content was 6% higher in second year compared with compared with first year. The C x NL interaction indicated that increasing N from 80 upto 120 kg ha^{-1} increased the glucosinolates contents in all cutting treatments. However, the glucosinolates were markedly lower in C_3 and C_2 than C_1 under NL_1 (Figure 4).

Table 8. Canola glucosinolates content (μ mol g^{-1}) as affected by cutting treatments, nitrogen levels and application timings under varying planting densities.

Variables.	2012–2013	2013–2014	Two Years Average
Cutting treatments (C)			
C_1	59.97 b	66.18 a	64.48 a
C_2	62.78 a	63.67 b	61.82 b
C_3	58.03 c	62.46 b	60.25 c
LSD $_{(0.05)}$	1.88	1.91	1.26
Nitrogen levels (NL)			
NL_1	57.59 b	61.42 a	59.61 b
NL_2	62.93 a	66.79 b	64.86 a
Significance level	*	*	*
N application timings (NT)			
NT_1	60.07	63.74	62.45
NT_2	60.27	64.26	62.23
NT_3	60.45	64.32	61.87
LSD $_{(0.05)}$	1.07	1.51	0.99
Planting density (PD)			
PD_1	60.76	64.29	62.11
PD_2	59.76	63.93	62.26
Significance level	ns	ns	ns
Year (*)	60.26 b	64.11 a	

Note: Cuttings (C): no-cut (C_1), cutting (C_2), grazing (C_3); Nitrogen levels (NL) 80 kg ha^{-1}(NL_1), 120 kg ha^{-1} (NL_2); Nitrogen timings: Full application at sowing (NT_1), half dose of N both at sowing and start of rosette stage (NT_2), one third dose of N each at sowing, start of rosette stage and soon after cut at late rosette stage (60 days after sowing (NT_3); Planting density (PD): 20 plants m^{-2} (PD_1), 40 plants m^{-2} (PD_2). Means of the same category followed by different letters are significantly different at 5 % level of probability using LSD $_{(0.05)}$ test. ns = non-significant, * = Significant at 5% level of probability.
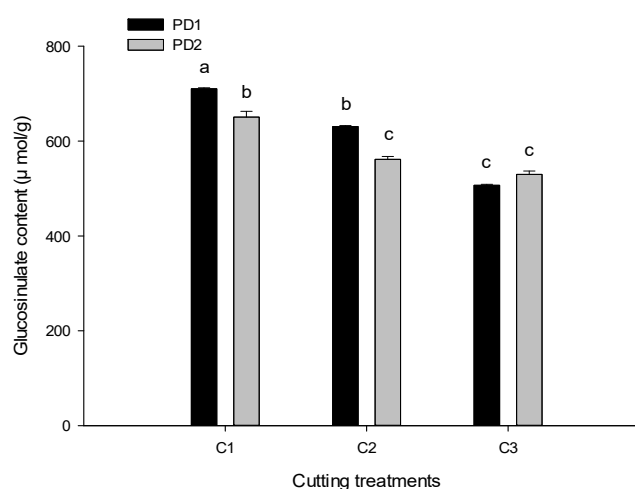

Figure 4. Interaction between cutting treatments and nitrogen levels for glucosinulates content. Vertical bars represent Standard Error. Note: Cuttings (C): no-cut (C_1), cutting (C_2), grazing (C_3); Planting density (PD): 20 plants m^{-2} (PD_1), 40 plants m^{-2} (PD_2).

3.4. Economic Analysis

Economic analysis showed that C_2 produced higher net income (USD 1202.1) compared to that of C_1 (USD 1057.2) (Table 9). However, in C_1 plots net income was higher compared to C_3 (USD 121). C_2 and C_3 plots reduced grain yield by 15% and 23%, respectively, than C_1 plots. Likewise, value cost ratio (VCR) of C_2 was higher compared with C_3 and C_1 plots. Furthermore, higher VCR (4.16) was found in C_2 where N at the rate of 80 kg ha^{-1} in NT_2 with high density (40 plants m^{-2}) was followed by C_2 and received at NL_1 with PD_2. The lower VCR (1.58) in C_3 received at NL_2 in NT_3 in PD_1 (Table 10). The net income from fodder of canola in C_2 plots were recorded on the basis of area as per usual practice at the same farm.

Table 9. Economic analysis of dual-purpose canola.

Yield, Value or Cost	C_1	C_2	C_3
Forage yield (kg ha^{-1})	0.0	13.9	14.1
Grain yield (kg ha^{-1})	12.4	10.5	9.5
Straw yield (kg ha^{-1})	92.1	74.3	63.8
Forage value (USD)	0.0	69.5	70.3
Grain value (USD)	884.5	1067.1	863.4
Straw value (USD)	552.4	446.1	383.1
Gross income (USD)	1436.9	1582.8	1316.9
Net income over control (USD)	1057.2	1202.1	936.2
Value cost ratio (VCR %)	2.78	3.1	2.4

Note: Cuttings (C): no-cut (C_1), cutting (C_2), grazing (C_3).

Table 10. The interactive effects of different factors over economic benefits (VCR values).

Plant density m^{-2}	Cutting	N rate	NT_1	NT_2	NT_3
PD_1	C_1	NL_1	2.95	2.57	2.82
	C_1	NL_2	2.59	2.21	2.71
	C_2	NL_1	3.00	3.35	3.00
	C_2	NL_2	2.71	3.36	3.17
	C_3	NL_1	3.09	3.35	2.92
	C_3	NL_2	2.85	2.22	1.58
PD_2	C_1	NL_1	2.60	3.30	3.10
	C_1	NL_2	3.02	2.69	2.80
	C_2	NL_1	3.52	4.16	2.57
	C_2	NL_2	3.22	3.06	2.83
	C_3	NL_1	2.18	2.63	2.07
	C_3	NL_2	2.59	2.23	1.96

Note: Cuttings (C): no-cut (C_1), cutting (C_2), grazing (C_3); Nitrogen levels (NL) 80 kg ha^{-1}(NL_1), 120 kg ha^{-1} (NL_2); Nitrogen timings: Full application at sowing (NT_1), half dose of N both at sowing and start of rosette stage (NT_2), one third dose of N each at sowing, start of rosette stage and soon after cut at late rosette stage (60 days after sowing (NT_3); Planting density (PD): 20 plants m^{-2} (PD_1), 40 plants m^{-2} (PD_2).

4. Discussion

4.1. Crop Yield

4.1.1. Effects of Grazing and Cut on Canola Yield

Biological yield is the function of increase rate and growth duration both of which indicate the possibility for improved yield. In this study, biological yield was higher in no-cut plots followed by cut and grazed plots. Biological yield recovered rapidly in cut and grazed plots but the removal of branches in initial grazing and cuttings had led to the differences among the means. Delay in flowering may affect biological yield, when grazing removed the main auxiliary buds from the stems [15]. In our study biological yield was higher in second year (2013–2014) compared with first year (2012–2013),

might be due to that in the second year, canola was sown for 15 days earlier than first year. Earlier sown plans of dual-purpose cropping for better results [16]. Reduction in biological yield was associated with the removal of branches in flowering, and not affected on seed yield [17]. Gross marginal value of DP canola is greater than grains only. In most cases grazing during early growth stages does not show significant results in the reduction of seed yield [18,19], while grazing after vegetative stage caused reduction up to 25% or even more [15,16]. Cutting treatments caused significant reduction in grain yield, might be due to less re-growth ability of plants in cut and grazed plots, and they were unable to regenerate quickly and reach to the growth of plants of no cut plots. The possible reason for this substantial decrease in yield of grazed and cut plots might be the removal of main stem either manually or by sheep grazing.

4.1.2. Effects of N fertilizer, Application Timings on Canola Yield

Canola crop responded well to N application timings. In these experiments, 3% and 1% increase in biological yield of canola was recorded in plots where N was applied in two or three splits as compared with sole application, respectively. The increase in yield with split application of N at seedling, rosette stage and early flowering [20]. Similarly, application of N at the rate of 100 kg ha^{-1} in split form (half each at sowing and soon after grazing) increased the biological yield up to 3.95 t ha^{-1} [21], and nitrogen in split form resulted better than sole application [22].

Canola crop requires high amount of N fertilizer compared to cereals to produce high yields [23]. In our study, seed yield increased by 6 % when N rate mounted from 80 to 120 kg ha^{-1}. Higher yields of canola achieved in the current study also highlights the high levels of N fertilizer which must be applied to achieve enhanced seed yield. In general, for canola crop 80 kg N ha^{-1} may be applied in the growing season for each 1 t/ha predictable yield [21]. Several studies observed no significant results with further (200 kg ha^{-1}) increase in N levels [3,24]. While, in our study, the improvement in grain yield can be attributed to N fertilizer at 120 kg ha^{-1} in two splits half at sowing while remaining at rosette stage. The split application of N fertilizer provides flexibility in their fertilizer program, and attracts farmers. Further, higher grain yield was noted in plots where N was applied in two splits as compared with single fertilization of N. The splits application of N fertilizer benefited crop growth and ensure availability of nutrients at two splits, one at sowing and second at rosette stage which may result in higher grain yield of faba bean [25,26].

4.1.3. Effects of Planting Densities on Canola Yield

Optimum planting is important to attain high yield and is a best option for reducing lodging among the plants. Biological yield increased by 3.3% with planting density of 40 plants m^{-2} compared to 20 plants m^{-2}. This difference may be mainly due to increase in plants per unit area. Dahmardeh et al. compared three planting densities (12.5, 16.7, and 20 plants m^{-2}) and found that biological yield of canola was highest for 20 plant m^{-2} compared to other planting density [27]. The inter-competition for nutrients among the plants might be a reason for the lower biological yield. Planting density is an important factor which determines the yield and which is individually affected by the climatic conditions and production system of an area as well [28]. In our study, planting density had non-significant effects on grain yield which indicated that 20 and 40 plants m^{-2} gave same results for grain yield of canola. However, higher yield in least densities indicated the proper utilization and maximum facilitation of nutrients [3].

4.2. Qualitative Traits of Canola

4.2.1. Effects of Grazing and Cut on Quality Traits of Canola

The improvement in quality of seed is the primary objective of breeding oil seed crops to fulfill upcoming edible oil requirements [29]. Oil content is mainly related with genetics for most of the species and varieties but the role of environment cannot be ignored. Cutting and grazing declined

oil content of canola. We do not agree with the findings of Kirkegaard et al. that allowing sheep for grazing before bud elongation had no impact on oil content of canola seed [16]. Protein content in cut plots was higher than no cut and grazed plots while, glucosinolates was maximum in no cut plots compared to grazed and cut plots. However, year had significant effect on oil content of canola. Almost 113.6% higher oil content was recorded in second year compared to that of first year. Likewise, in second year protein content was increased up to 161.9% as compared to first year.

4.2.2. Effects of N Fertilizer, Application Timings on Quality Traits of Canola

The N fertilizer had a negative correlation with oil content of the seeds [30,31]. Increasing N level from 80 to 120 kg ha^{-1} decreased the oil content of canola seed. Likewise, higher oil content was measured in plots where N was applied in splits compared with sole N application. Further, seed oil content of canola reduced significantly with increase in N levels from 0 to 200 kg ha^{-1} [32,33], and the highest oil content (43.08%) in plots with low N rates (50 kg ha^{-1}) while lowest oil content (38.64%) was recorded with high levels of N fertilizer (200 kg ha^{-1}) [34]. However, the reduction in oil content due to increase in N levels [31,34]. For example, the accessibility of sugar for oil synthesis becomes less with increase in N rates, that the application of high rates of nitrogen fertilizer increased the amount of N containing protein; so this protein development goes through a competition for photosynthesis, as a consequence of less amount of the later is obtainable for fats production [32,35,36]. This inverse relationship between oil and protein content with increase in N levels may also be the possible reason [37]. However, our data did not agree with the findings of Brennan et al. (2000) who concluded that oil content is not going to decrease with increased in N rates [38]. It is also noticeable that protein content of canola seed improved with rising levels of nitrogen.

Nitrogen is the integral part of protein structures and involved in many other plant metabolic processes. Thus, increasing N levels increased the protein content of canola seeds. N at 120 kg N ha^{-1} application had higher protein content over 80 kg ha^{-1}. The higher protein value is the evidence of negative correlation between oil content and protein content. Both these are inversely proportional to each other [6]. Increased N supply helps in increasing protein synthesis without compromising oil content reduction [18]. Similarly, split application resulted in higher protein contents compared with sole N application. The protein content of canola increased from 22.7% to 23.7% with the increasing N rates from 80 to 160 kg ha^{-1} [39]. Glucosinolates contents were significantly affected by N levels but N application timing had a non-significant effect on glucosinolates contents. Glucosinolates contents increased from 59 to 64 μmol g^{-1} with increasing N from 80 to 120 kg ha^{-1}. These data indicated that increasing N levels significantly increased glucosinolates contents. The increase in glucosinolates contents due to N fertilization was also reported by [35,40–42]. Glucosinolates structure contains N therefore high N concentration may be influenced by the addition of N fertilizers [43].

4.2.3. Effects of Planting Densities on Quality Traits of Canola

Competition among the plants due to high planting density can result in poor quality attributes, impairs plant growth, reduced biomass formation, and consequently yield loss due to low nutrients uptake, and disruption in leaf structural and functional characteristics [44–46]. Increasing density decreases oil content may be due to inter plant competition for nutrients. Plants grown at 40 plants m^{-2} had higher oil content compared to 20 plants m^{-2}. In contrary, no significant variation in oil content with increase in planting densities from 45 to 80 plants m^{-2} [47].

4.3. Interaction Effect of Factors

The proper nutrients at proper time to any crop is important [6], and canola crop requires a higher amount of nutrients, and available nitrogen (N) compared with that of cereals [7]. Split application of N fertilizer has become more popular in terms of high nitrogen use efficiency. Therefore, an appropriate rate and timing of N fertilizer application is one of the most important aspects of successful canola

production [3]. These findings support our results that the interactive effects of NL2 with NT2 at PD1 were more qualitative and productive for canola under dual purpose.

4.4. Economics Benefits

The effectiveness of dual-purpose canola can be predictable by the economic analysis of no-cut, cut and grazing systems. Cut plots produced higher net income as compared to no-cut and grazed plots. The higher net income and thus higher value cost ratio (VCR) value of cut plots was due to high fodder and grains as compared to no-cut system. However, grazed plots reduced VCR value by 10% and net income by 69% as compared to no-cut plots. Our results are against with the findings that higher net income ($240 to $500) for grazed plots as compared to no-cut or grains only system [47].

5. Conclusions

The study revealed that integration of DP cropping would increase farm productivity, profitability and flexibility of the farm operations. It is an innovation which captures more food by increasing crop and livestock production on the same farm. C_2 caused a 15% reduction in grain yield of canola; however, it fetched additional income of USD 143.6 compared to C_1. In case of C_3, 23% reduction was resulted in grain yield of canola with income of USD 117.7 from fodder yield of the same canola. Treatment NL_2 produced higher seed yields and improved quality traits of canola compared with NL_1. Further, NL_2 increased grain yield and qualitative parameters of canola. Crops under PD_2 produced more biological yield compared to PD_1. However, seed yield was higher at PD_1. Dual purpose cropping is a classical way which can contribute to continued development of sustainable agriculture systems. Currently, Pakistan is facing a serious shortage of edible oils and food insecurity threats. Therefore, the use of application of N in two splits at 120 kg N ha^{-1} coupled with 20 plants m^{-2} is a good option to achieve better qualitative attributes and high yield of canola under dual purpose system.

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