

# Grazed rain-fed small-grain cereals as a forage option for small-scale dairy systems in central Mexico

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## Research Article

**Keywords:** Alternative forages, rye, triticale, wheat, small-scale dairy farming.

**Posted Date:** June 22nd, 2021

**DOI:** <https://doi.org/10.21203/rs.3.rs-617769/v1>

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# Abstract

Small-scale dairy systems face reduced availability of water for irrigation of pastures and disruption in the amount or pattern of rains due to climate change, so research on alternative short-cycle rain-fed forages is needed. Grazing reduces feeding costs and small-grain cereals may be an option. The objective was to assess on-farm the performance of dairy cows grazing 6 h/d of three small-grain cereals: rye (RYE), wheat (WHT), and triticale (TRT), and supplemented 4.5 kg DM/cow/d of concentrate. Twelve Holstein cows were used in repeated 3x3 Latin Squares with 14-day experimental periods. Pasture variables were analysed with a split-plot design, and economic analysis was performed with partial budgets. Sampling of forage (sward height, net herbage accumulation, botanical and chemical composition of herbage) and animal variables (milk yield and composition, live weight, and body condition score) were at the end of each period. RYE showed a trend ( $P = 0.10$ ) for higher net herbage accumulation with highly significant differences ( $P < 0.001$ ) among periods. RYE had higher DM, a lower CP content ( $P < 0.05$ ) and no differences for other chemical components between treatments ( $P > 0.05$ ). RYE proportion in pasture was consistently higher, whilst the lowest cereal proportion was in WHT. There were no differences ( $P > 0.05$ ) for any animal variable. The RYE and TRT treatments proved useful as rain-fed forage alternatives under grazing. WHT showed lower crop and economic performance. However given the higher cereal component in pastures, regrowth potential, post-grazing herbage mass, as well as better economic performance, the RYE treatment was better ranked by the participating farmer.

## Introduction

Small-scale cattle systems improve livelihoods worldwide by increasing simultaneously the assets of farming families and resilience to climatic, health and economic risks (Blümmel et al. 2015).

In Mexico, over 88% of all farms with cattle are small (INEGI 2018), while small-scale dairy systems contribute more than 30% of the national milk production, and they enable families to overcome rural poverty (Espinoza-Ortega et al. 2007).

The sustainable intensification of small-scale livestock systems is promoted to improve their contribution to livelihoods, food security, and to reduce the environmental footprint (Makkar 2016; FAO 2017); such intensification enables small-scale farmers to better commercialise their produce and increase their income (Rasmussen et al. 2020). In small-scale diversified livestock-crop systems may provide both high productivity and ecosystem services to mitigate the environmental footprint (Lemaire et al. 2014).

Grazing irrigated pastures has shown reduced feeding costs and increased profitability in small-scale dairy farms in central Mexico (Prospero-Bernal et al. 2017). However, water for irrigation is becoming scarce limiting the feasibility of long term pastures, a situation that will worsen due to possible effects of climate change with disruptions in the amount and patterns of rainfall in the highlands of Mexico (Ortiz-Espejel et al. 2015).

Therefore, there is a need to assess alternative forage species better adapted to rain-fed conditions with low water requirements, which may be implemented in small-scale systems with a view to improving their

productivity without increasing their environmental footprint (Lemaire et al. 2014).

Small-grain cereals (Payne et al. 2008) meet these requirements, since their short agronomic cycle requires less water than permanent pastures or long cycle annual crops such as maize, plus small-grain cereals are hardy and frost resistant.

Their successful use as silage to complement grazing during dry season in small-scale dairy systems has been documented (Celis-Alvarez et al. 2016; Burbano-Muñoz et al. 2018; Gómez-Miranda et al. 2020; González-Alcántara et al. 2020); and they may offer a rain-fed alternative for these systems in the rainy season.

Aasen et al. (2004) reported that grazing small-grain cereals in Canada is an option that may be resorted to as an emergency feed or to extend the grazing season in dry years. Another benefit is that grazing small-grain cereals is a means to improve soil fertility through nutrient cycling (Henz et al. 2016).

McCartney et al. (2008) mentioned that grazing of small-grain cereals for beef cattle in Canada was implemented more than a hundred years ago to extend grazing seasons, reduce feeding costs, and mitigate climatic effects (mainly dry years).

Over 45 years ago, in an assessment of small-grain cereals as a forage source, Fisher and Fowler (1975) indicated that when assessing small-grain cereals for forage it was not only necessary to take dry matter (DM) yields into account, but also the nutritional value of the forage for the livestock to feed.

Wheat (*Triticum spp.*) is the most widely cultivated cereal grain in the world. It has an ample adaptation range, growing in diverse environments and may be sown as a fall or spring crop (Soto et al. 2009), and it has been used as a dual purpose (grain and grazing) crop to overcome feed shortages in Brazil.

Rye (*Secale cereale*) has been used as a double purpose crop in Canada, as a grazed forage source in fall, spring or both seasons, and then left to grow for a grain harvest (Kilcher 1982). Fisher and Lessard (1987) stated that forage yield and digestibility make it a useful option for ruminant feeding.

Triticale (*X Triticosecale Wittmack*) is an intergeneric hybrid bred to conserve the quality and grain yield of wheat with the hardiness of rye (McCartney et al. 2008). In Mexico, triticale has been promoted as a possible forage for conservation given its resistance to low temperatures, drought, pests and disease, as well as reduced loss of nutritive value as it matures (Ballesteros-Rodríguez et al. 2015; González-Alcántara et al. 2020).

Small-grain cereals are reported for good yields of quality forage on short agricultural cycles that represent an alternative to grazing pastures (GRDC 2018), so the characteristics of these crops (Payne et al. 2008) meet the criteria to be included in cattle feeding strategies better adapted both to current situations of restriction in the availability of irrigation, and in the future possible lower rainfall and disrupted rain patterns due to climate change (Thornton et al. 2009).

Although small-grain cereals have been evaluated as conserved forages, wheat, rye and triticale have not been estimated under grazing in Mexico. Therefore, the objective was to assess the yield of these cereals and dairy cow performance under grazing for small-scale dairy systems.

## Materials And Methods

Work was an on-farm experiment with a collaborating small-scale dairy farmer in accordance with guidelines for participatory livestock technology development (Conroy, 2005), in the municipality of Aculco, State of Mexico, Mexico (20°10' N, 99°48' W; 2470 m altitude) in the central highlands.

The adoption of innovations increases when farmers participate in research, not only providing their knowledge on the farming system, but also the social, economic, and cultural contexts that eventually determine adoption (Garcia et al. 2018).

The collaborating farmer actively participated in the experiment, had knowledge of the objectives, was duly informed and consulted. and his decisions were respected at all times. The experiment was undertaken on the farmers' farmland, with cows from his herd and under his management conditions.

### Cereal crops

Three one-hectare contiguous plots were sown on 20 May 2020 each to one cereal: rye (*Secale cereale*) cv. Nacional; wheat (*Triticum aestivum*) cv. Tollocan-F05; and triticale (X. *Triticosecale Wittmack*) cv. Bicenetenario. For all the cereals, the seed was broadcasted at a sowing rate of 140 kg/ha.

Fertilisation at sowing was 23 N – 60 P – 40 K /ha; a second fertilisation took place 19 days after sowing with 57 kg N/ha as urea; and a third one, 44 days after sowing with 23 kg N/ha. This way, total fertilisation was 103 N – 60 P – 40 K kg/ha.

The grazing experiment started on day 65 after sowing, i.e., 24 July 2020, when the cereal crops were at least 25 cm in height.

### Forage variables

Net herbage accumulation (NHA) was estimated with six exclusion cages per treatment (cereal crop) cutting to ground level with shears all herbage within 0.4 x 0.4 m metal squares outside the cages on day 1, and inside the cages at the end of each experimental period. Sward height was recorded with a rising plate grass-metre and with a measuring tape (Plata Reyes et al. 2018; Vega-García et al. 2020).

For chemical analyses, hand-plucked samples of herbage simulating grazing were taken at the end of each experimental period (Morales et al. 2018). Determinations of dry matter (DM), organic matter (OM), crude protein (CP), neutral detergent fibre (NDF), acid detergent fibre (ADF), and *in vitro* dry matter digestibility (IVDMD) were by standard methods following Celis-Alvarez et al. (2016). Estimated metabolizable energy content (eME) was from AFRC (1993).

Botanical composition was from five random samples per crop, cutting to ground level within a 0.4 x 0.4 m metal square and manually separating herbage into: cereal crop, grasses, other plants, and dead tissue; dried in a draught oven at 55°C for 48 h; results were reported as g/100 g DM (Sanderson et al. 2005).

### **Treatments and animals**

The experimental design was a 3x3 Latin Square repeated four times with the following treatments: continuous day grazing of rye crop (RYE), wheat (WHT) or triticale (TRT) for 6 h/d (9:00 to 15:00h). Treatment sequence was randomly assigned; also each cow within each group (Latin Square) was randomly assigned to treatment sequence.

Additional to grazing, each cow received 4.5 kg DM/day of a commercial dairy concentrate, split in two meals of half the allocation after morning (7:30 h) and evening (18:00) milkings, which were carried out manually.

Grazing time and concentrate supplementation were decided by the participating farmers.

Twelve Holstein cows were used in the experiment in groups of four cows each (for each Latin Square), similar in terms of parity, days in milk, daily milk yield and live weight. Mean pre-experimental variables were  $3.6 \pm 0.49$  calving/cow daily milk yield (MY) of  $14.5 \pm 1.19$  kg/cow/d,  $120.5 \pm 23.70$  days in milk,  $459.5 \pm 13.00$  kg live weight (LW), and  $1.7 \pm 0.05$  body condition score (BCS) on a 1 to 5 scale.

### **Animal variables**

Animal variables were recorded following Gómez-Miranda et al. (2020). Milk yield was recorded daily over the last four days using a clock spring balance with a 20 kg capacity, and an aliquot sample refrigerated until analyses for milk fat, protein, and lactose content with an ultrasound milk analyser. Milk yield was corrected to 3.5% fat content following Dairy Records Management Systems (2014) and Plata-Reyes et al. (2021). Analyses for milk urea nitrogen (MUN) were by the enzymatic colorimetric method (Chaney and Marbach 1962), as reported in previous works (Celis-Alvarez et al. 2016; Plata-Reyes et al. 2018; 2021).

Live weight (LW) was recorded during the last two consecutive days at the end of each experimental period with an electronic weighbridge, while body condition score (on a 1 to 5 scale), on the last day of each period, always by the same observer.

### **Economic analyses**

Partial budget analyses were run considering only feeding (including cropping) costs, and margins over feeding costs as in previous works (Celis-Alvarez et al. 2016; Prospero-Bernal et al. 2017; Gómez-Miranda et al. 2020).

### **Experimental design**

The experiment, for animal and economic variables, followed a 3x3 Latin Square design repeated four times (Kaps and Lamberson 2004), with 14-day experimental periods (10 days for adaptation and 4 days for sampling).

Latin square designs are useful for research on feeding strategies for dairy cows as they enable maximising a small number of available experimental units (Ribeiro-Filho et al. 2021) in on-farm experiments with small-scale farmers; and short experimental periods are well validated in the scientific literature (Pérez-Prieto et al. 2013; Miguel et al. 2014).

The model for the statistical analyses of animal and economic variables was (Burbano-Muñoz et al. 2018):

$$Y_{ijkl} = \mu + S_i + C_{j(i)} + P_k + t_l + e_{ijkl}$$

Where:  $\mu$  = general mean;  $S$  = effect due to squares.  $i = 1, 2, 3, 4$ ;  $C$  = effect due to cows in squares  $j = 1, 2, 3$ ;  $P$  = effect due to experimental periods.  $k = 1, 2, 3$ ;  $t$  = effect due to treatment  $l = 1, 2, 3$ ; and  $e$  = residual error term.

The experimental design for crop variables was a randomised split-plot design with crop subdivisions as experimental units, crops as main plots, experimental periods as split-plots, and samplings (inside and outside the exclusion cages) as replicates within crop subdivisions, resorting to the model below for statistical analyses (Plata-Reyes et al., 2021):

$$Y_{ijkl} = m + csd_i + T_j + E_k + p_l + Tp_{jl} + Tr_{jm} + e_{ijk}$$

Where:  $m$  = general mean;  $csd$  = effect of crop subdivision  $i = 1,2,3$ ;  $T$  = effect of crop (small-grain cereal) treatment (Main Plot)  $j = 1, 2, 3$ ;  $E$  = error term for main plots [ $csd(T)ij$ ];  $p$  = effect of experimental periods (split-plot)  $k = 1, \dots, 3$ ;  $Tp$  = interaction term between treatments and measurement periods;  $Tr$  = interaction term between treatments and sampling replicates ( $r_m = 1,2$ );  $e$  = experimental error term.

## Results

Figure 1 shows meteorological conditions in the study area during the experiment. Although there was adequate rainfall (mean of 127 mm per experimental period), it tended to decrease by the end of the experiment. Mean maximal and minimal temperatures were 24.5°C and 10.6°C, respectively.

### Crop variables

Table 1 shows that RYE had a trend ( $P = 0.10$ ) for the highest net herbage accumulation per period over the experiment with 2.8 ton DM/ha/period; whilst WHT accumulated 1,000 kg DM/ha/period less than RYE, and TRT exhibited an intermediate yield.

Table 1

Net herbage accumulation (NHA) and sward height of small-grain cereal crops.

	Treatment Means	SEMt	Experimental Periods			SEMp	P <sub>t</sub>	P <sub>p</sub>
			1	2	3			
<b>NHA (kg DM /ha/ period)</b>								
RYE	2806	424.0	879	4470	3069	1278.5	0.106	0.001
WHT	1806		1070	2790	1559			
TRT	2359		1062	3407	2607			
Period means			1003	3556	2412			
Interaction SEM <sub>t</sub> * <sub>p</sub>						210.0 <sup>NS</sup>		
<b>NHA (kg DM /ha /d)</b>								
RYE	200	30.2	62	319	219	91.3	0.106	0.001
WHT	129		76	199	111			
TRT	168		76	243	186			
Period means			71	254	172			
Interaction SEM <sub>t</sub> * <sub>p</sub>						15.0 <sup>NS</sup>		
<b>Height GM (cm)</b>								
RYE	36 <sup>a</sup>	7.6	30	38	40	6.5	0.003	0.006
WHT	19 <sup>b</sup>		16	19	23			
TRT	24 <sup>ab</sup>		18	25	28			
Period means			21	27	30			
Interaction SEM <sub>t</sub> * <sub>p</sub>						1.2 <sup>NS</sup>		
<b>Height MT (cm)</b>								
RYE	81 <sup>a</sup>	22.8	67	83	94	12.8	0.000	0.004
WHT	33 <sup>b</sup>		26	34	39			
TRT	43 <sup>ab</sup>		29	42	56			
Period means			41	53	63			
Interaction SEM <sub>t</sub> * <sub>p</sub>						2.3 <sup>NS</sup>		

	Treatment Means	SEMt	Experimental Periods			SEMp	P-t	P-p
			1	2	3			
<b>Note:</b> <sup>a,b</sup> = ( $P < 0.05$ ), <sup>NS</sup> = ( $P > 0.05$ ), NHA = net herbage accumulation, GM = grass metre, M = measuring tape, RYE = rye crop, WHT = wheat crop, TRT = triticale crop, SEMt = standard error of the mean for treatments, SEMp = standard error of the mean for periods, SEMt*p = standard error of the mean of interaction. P-t = Probability value for treatments, P-p = Probability value for experimental periods.								

There were highly significant differences ( $P < 0.001$ ) among experimental periods for the three crops, with the lowest NHA in period 1 and the highest in period 2. RYE also had the higher sward height of the three cereals ( $P < 0.05$ ).

RYE showed the best yield in spite of the haphazard rain with dry spells during the experiment; and a greater NHA was from the cereal not from the spontaneous grass or other plants as was the case in WHT (Table 2).

Table 2

Botanical composition of small-grain cereal crops in g/100 g MS

Variable	Treatments			Mean	SEMt	Experimental periods			Mean	SEMp
	RYE	WHT	TRT			1	2	3		
<b>Cereal</b>	78.9 <sup>a</sup>	19.3 <sup>c</sup>	40.7 <sup>b</sup>	46.3	3.3 <sup>***</sup>	46.3	48.0	44.7	46.3	3.3 <sup>NS</sup>
<b>Grass</b>	2.1 <sup>b</sup>	13.6 <sup>a</sup>	5.4 <sup>b</sup>	7.1	1.8 <sup>**</sup>	5.0	7.5	8.6	7.0	1.8 <sup>NS</sup>
<b>Other plants</b>	14.7 <sup>b</sup>	61.1 <sup>a</sup>	50.8 <sup>a</sup>	42.2	4.0 <sup>***</sup>	44.1	41.5	40.9	42.2	4.0 <sup>NS</sup>
<b>Dead tissue</b>	3.7	5.8	2.9	4.1	1.3 <sup>NS</sup>	4.4	2.8	5.1	4.1	1.3 <sup>NS</sup>
<b>Note:</b> <sup>a,b</sup> ( $P < 0.05$ ), <sup>**</sup> = $P < 0.01$ ; <sup>***</sup> = $P < 0.001$ ; <sup>NS</sup> = ( $P > 0.05$ ), RYE = rye crop, WHT = wheat crop, TRT = triticale crop, SEMt = standard error of the mean for treatments, SEMp = standard error of the mean for periods.										

In botanical composition, over the experiment there was a greater presence of cereal in RYE (mean 78.9%) in comparison with the other two treatments, WHT (mean 19.4%) and TRT (mean 40.8%). In RYE, the presence of cereal decreased as the experiment progressed, while the presence of other plants remained constant (mean 15.2%).

The presence of other plants in WHT was higher over the entire experiment (mean 61.2%), with the highest presence of cereal in period 1 with only 21.5%. It is worth mentioning that the presence of grass increased as periods passed, surpassing the proportion of wheat in period 3 when the cereal accounted only for 18.4% of DM.

In TRT the presence of other plants was also high, even though in this case the presence of cereal was twice as much in comparison with WHT. For this treatment, grass in the crop reached a peak in value in period 2 (7.6%); and the presence of dead tissue was minimal (mean 3.4%) (Table 2).

The various growth stages of the cereals influence their chemical composition. RYE was at a more advanced growth stage given its early vigorous growth, so that its DM content was higher than those of WHT and TRT. This stage of growth also caused that CP content was 10% lower in RYE ( $P < 0.05$ ) in comparison with the other treatments; albeit, there were no differences ( $P > 0.05$ ) in relation to NDF and ADF and IVDMD. There were differences in all the variables of chemical composition among periods ( $P < 0.05$ ) except for NDF (Table 3).

Table 3

Chemical composition of small-grain cereal crops and concentrate.

Treatment/variable	Experimental Periods			Mean Tx	SEMt	SEMp	P <sub>t</sub>	P <sub>p</sub>
	1	2	3					
<b>DM (g/kg DM)</b>								
RYE	232	262	289	261 <sup>a</sup>	19.0	22.0	0.000	0.000
WHT	206	212	250	223 <sup>b</sup>				
TRT	207	259	262	242 <sup>a</sup>				
Period means	225	235	267					
Concentrate	896							
Interaction SEMt* <sub>p</sub>					7.0		0.002	
<b>OM (g/kg DM)</b>								
RYE	949	923	929	934 <sup>a</sup>	4.0	5.9	0.000	0.000
WHT	928	925	927	927 <sup>b</sup>				
TRT	929	922	929	926 <sup>b</sup>				
Period means	935	923	928					
Concentrate	985							
Interaction SEMt* <sub>p</sub>					2.3		0.000	
<b>CP (g/kg DM)</b>								
RYE	153	133	123	136 <sup>b</sup>	8.4	29.0	0.028	0.000
WHT	190	141	115	149 <sup>a</sup>				
TRT	190	142	117	150 <sup>a</sup>				
Period means	178	139	118					
Concentrate	206							
Interaction SEMt* <sub>p</sub>					3.9		0.049	
<b>NDF (g/kg DM)</b>								
RYE	614	639	497	550	14.2	8.2	0.068	0.260
WHT	518	582	582	561				

Treatment/variable	Experimental Periods			Mean Tx	SEMt	SEMp	P-t	P-p
	1	2	3					
TRT	536	520	541	532				
Period means	556	547	540					
Concentrate	236							
Interaction SEMt*p					16.2		0.005	
<b>ADF (g/kg DM)</b>								
RYE	329	280	258	289	10.7	22.9	0.138	0.013
WHT	243	304	299	282				
TRT	266	261	277	268				
Period means	280	282	278					
Concentrate	94							
Interaction SEMt*p					7.2		0.084	
<b>IVDMD (g/kg DM)</b>								
RYE	737	696	659	697	2.3	36.4	0.969	0.043
WHT	743	722	675	713				
TRT	719	698	683	700				
Period means	733	705	672					
Concentrate	889							
Interaction SEMt*p					6.7		0.586	
<b>eME (MJ/kg DM)</b>								
RYE	9.83	9.29	8.80	9.31	0.7	0.3	0.617	0.066
WHT	9.91	9.64	9.02	9.52				
TRT	9.59	9.32	9.12	9.34				
Period means	9.77	9.41	8.98					
Concentrate	11.85							
Interaction SEMt*p					0.05		0.844	

Treatment/variable	Experimental Periods			Mean Tx	SEMt	SEMp	P <sub>t</sub>	P <sub>p</sub>
	1	2	3					

**Note:** <sup>a,b</sup> ( $P < 0.05$ ), DM = dry matter, OM = organic matter, CP = crude protein, NDF = neutral detergent fibre, ADF = acid detergent fibre, IVDMD = *in vitro* dry matter digestibility, eEM = metabolizable energy, RYE = rye crop, WHT = wheat crop, TRT = triticale crop, SEMt = standard error of the mean for treatments, SEMP = standard error of the mean for periods, SEM<sup>t</sup>\*p = standard error of the mean of interaction.

### Animal variables

Table 4 shows results for animal variables. There were no significant differences ( $P > 0.05$ ) for any evaluated animal performance variable between treatments as milk yield, live weight, or body condition score; although results for live weight and body condition score are only indicative as the short experimental periods preclude any other interpretation for these variables.

Table 4  
Productive performance of cows grazing small-grain cereal crops.

Variable	Treatments			SEM	P value
	RYE	WHT	TRT		
3.5% FCM (kg/cow/day)	13.5	13.4	13.3	0.16	0.38
LW (kg)	470.2	466.6	468.1	3.33	0.75
BCS (1–5)	1.9	1.8	1.9	0.08	0.91
Milk fat (g/kg)	37.8	37.0	38.2	0.06	0.18
Milk protein (g/kg)	27.9	28.7	28.3	0.01	0.38
Milk lactose (g/kg)	42.4	42.6	42.7	0.01	0.44
MUN (mg/dl)	16.1	16.3	16.0	0.54	0.92
Milk pH	6.6	6.5	6.6	0.01	0.92

**Note:** RYE = rye crop, WHT = wheat crop, TRT = triticale crop, 3.5% FCM = Milk yield (of 3.5 % fat corrected milk), LW = live weight, BCS = body condition score, MUN = milk urea nitrogen, SEM: standard error of the mean.

There were no differences ( $P > 0.05$ ) in milk composition for fat, protein, and lactose. There were no differences ( $P > 0.05$ ) either for MUN and for milk pH, which was reported as slightly acid.

DM intake during the experiment was similar ( $P > 0.05$ ) among treatments. The mean intake in pasture was 10.2 kg DM cow/d and mean total intake was 14.6 kg DM/cow/d (Table 5).

Table 5  
Dry matter intakes (kg DM/cow/day).

	Treatment			SEM
	RYE	WHT	TRT	
<b>Concentrate</b>	4.48	4.48	4.48	
<b>Pasture</b>	9.96	10.30	10.34	0.36 <sup>NS</sup>
<b>Total intake</b>	14.44	14.78	14.82	0.36 <sup>NS</sup>
<b>Note:</b> <sup>NS</sup> = $P > 0.05$ , RYE = rye crop, WHT = wheat crop, TRT = triticale crop, SEM: standard error of the mean.				

Table 6 shows results of the economic analyses for feeding costs (in USD\$). In the present experiment, treatments accounted for 25.6, 32.0 and 26.0% of the total feeding costs for RYE, WHT and TRT, respectively. RYE had the best income margins over feeding costs, although the income/feeding costs ratio in all treatments was above USD\$ 2.45.

Table 6

Economic analysis for different treatments in the experiment (USD\$)

Economic analysis	Treatments			SEM
	RYE	WHT	TRT	
<b>Feeding costs (USD\$)</b>				
Commercial concentrate	57.74	57.74	57.74	0.000 <sup>NS</sup>
Pasture	19.87 <sup>b</sup>	25.88 <sup>a</sup>	20.23 <sup>b</sup>	0.852 <sup>***</sup>
Total feeding costs	77.60 <sup>b</sup>	83.61 <sup>a</sup>	77.96 <sup>b</sup>	0.851 <sup>***</sup>
<b>Incomes</b>				
Total milk yield (kg)	697.92	709.80	693.00	7.031 <sup>NS</sup>
Feeding costs (USD\$/kg milk)	0.11	0.12	0.11	0.002 <sup>NS</sup>
Selling price (USD\$/kg milk)	0.30	0.30	0.30	0.000 <sup>NS</sup>
Income from milk sales (USD\$)	206.85	211.14	205.65	2.086 <sup>NS</sup>
Margin over feed costs (USD\$)	129.23	127.52	127.68	1.861 <sup>NS</sup>
Margin over kg of milk (USD\$/kg)	0.18 <sup>a</sup>	0.17 <sup>c</sup>	0.17 <sup>b</sup>	0.001 <sup>**</sup>
Income over feed costs (USD\$)	2.64 <sup>a</sup>	2.48 <sup>b</sup>	2.60 <sup>a</sup>	0.032 <sup>**</sup>
<b>Note:</b> <sup>a-b</sup> ( $P < 0.05$ ), <sup>**</sup> = $P < 0.01$ ; <sup>***</sup> = $P < 0.001$ ; <sup>NS</sup> = ( $P > 0.05$ ), RYE = rye crop, WHT = wheat crop, TRT = triticale crop, SEM = standard error of the mean.				

## Discussion

According to Soto et al. (2009), sowing date has a positive effect on the development of forages, as it defines the environmental conditions that plants will have along their life cycle. Additional to climate factors, others that intervene in the final yield of the crops are related to genetics and management.

In this experiment, the early sowing may have affected the poor forage performance of the cereal in WHT and TRT treatments (Table 2); where initial low rainfall from sowing to grazing may have slowed development in WHT (López-Bellido 1991).

The RYE treatment had a trend towards significant higher net forage accumulation per period, that over the whole experiment added up to 8.4 ton DM/ha for RYE, 19% over the 5.2 ton DM/ha for WHT, and TRT with an intermediate 7.6 ton DM/ha.

These forage yields were achieved in 107 days in total considering 65 days from sowing to the initiation of grazing, plus 42 days grazing (in three experimental periods), which at a stocking rate of 4 cows/ha meant 168 cow grazing days/ha.

Total forage accumulation during the experiment was higher than 5.6 ton DM/ha reported by Celis-Alvarez et al. (2017) for triticale and rye in the same study area, though in their work cereals were not used for grazing and were cut at 72 days after sowing.

McCartney et al. (2008) mentioned that rye has been recommended as an annual crop in dry zones, and produces more DM than triticale, which concurs with this work.

Wheat did not have an acceptable yield to be considered as an annual forage option for grazing in the study area when compared to RYE and TRT, even though it was recommended as a forage for annual pasture in Canada for drought prone areas given its water-deficit resistance (McCartney et al. 2008).

The WHT treatment in this work had a 1.0 ton DM /ha/period lower yield than RYE, and was severely invaded by grass and weeds. In this regard, Soto et al. (2009) mentioned that wheat for grazing must receive higher dosages of nitrogen fertilisation with a view to stimulating regrowth and not decreasing the final yield, for in a dual-purpose management, cultivations are subject to defoliation of varying intensities (in which forage offer, weight and number of animals take part) and frequencies, though regardless of the degree, it means stress for the plants.

For its part, net triticale accumulation per period was 2.7 ton DM /ha. The lowest NHA of the plant was for period 1 (Table 1). This is because in the pastures the presence of other plants and grass increased as periods passed (Table 2), though RYE, the treatment with the lowest NHA in Period 1, had a forage availability of 20.9 kg DM cow/d. For period 3, NHA decreased for the three treatments probably due to lower rainfall (Fig. 1).

Fisher and Fowler (1975) mentioned that the parameters of nutritional quality are influenced by the progressive stage of maturity up to the harvest day; in this case, the later maturing characteristics of WHT affected DM content in comparison with RYE and TRT. Conversely, the more advanced growth stage of RYE resulted in a lower content of CP ( $P < 0.05$ ), though CP for this cereal (136 g /kg DM) is 42% higher than the value reported by Celis-Alvarez et al. (2017). Although there were more days after sowing in the work herein reported compared to Celis-Alvarez et al. (2017), there was active regrowth in RYE after grazing.

Juskiw et al. (1991) assessed rye and triticale as monocultures associated with barley and observed a CP content over 190 g /kg DM for both cereals sown in the same season. WHT and TRT treatments had CP values similar to reports by Henz et al. (2016) and Khorasani et al. (1997).

In terms of IVDMD, there were no differences ( $> 0.05$ ) among treatments, though differences between periods were detected, with lower digestibility as time passed. Fisher and Fowler (1975) mentioned that chronological age as a maturity measurement does not accurately reflect physiological maturity, neither does a high DM yield mean it is necessarily digestible. The nutritional value of a forage is influenced by its energy content, and for its part, this is better ascertained by a digestibility measure.

The IVDMD values obtained in this work rank cereals as of medium quality, since Celis-Alvarez et al. (2017) reported digestibility for rye and triticale 5.5% higher. Henz et al. (2016) found lower values for wheat (615 g/kg DM) in relation to the IVDMD observed in the work herein reported.

Milk yields from grazing the cereals were similar to those obtained when grazing on grass-clover pastures in these small-scale production systems (Plata-Reyes et al. 2018; Carrillo-Hernández et al. 2020; Muciño-Álvarez et al. 2021). As there were no differences in DM intake or metabolizable energy content of forages, there were no differences in milk production (Ribeiro-Filho et al. 2021).

Grazing time and supplementation enabled a mean pasture DM intake of 10.2 kg DM/cow/day and a total mean DM intake of 14.7 kg DM/cow/day, representing 3.1% of mean live weight, indicating sufficient pasture in the small-grain cereal plots and that the 6 h access time for grazing did not restrict forage intake by cows, and that when access to pastures is reduced, cows increase time devoted to grazing to maximize intake in expense to rumination or idling time, as reported by Ribeiro-Filho et al. (2021).

The chemical composition of milk was within the parameters established by Mexican Standards for raw milk as regards to milk fat and protein contents. Lactose content was at the lower limit. According to Costa et al. (2019), the factors involved in lactose content are the number of lactations (with decreased lactose content with increased number of lactations; in this work, the average was 3.6 calvings/cow), days in lactation, as the lactose-content curve behaves as that of milk yield (the experiment began with 120 days in milk on average), somatic cell count and energy contained in feed.

According to Kohn et al. (2002), MUN contents were higher than recommended, since these authors stated that the adequate concentration level for this variable in dairy herds should be within the 8.5 to 11.5 mg/dL range; although values were within the range for normal MUN between 11 and 18 mg/dL contents reported by Powell et al. (2011) for cows in the USA. In the experiment herein reported it is possible that the diet might have had a higher protein content than requirements (Powell et al. 2011), albeit Aguilar et al. (2012) mentioned that there are a number of factors besides protein intake that may bring about variations in MUN content (sampling, season, weight and breed of the cows).

As for the economic analysis, McCartney et al. (2008) mentioned that under annual crop grazing, there are expenses at the beginning to afford machinery, fertilisers and seeds, plus tillage work in the fields. However, the advantage of grazing is that livestock collect their feed instead of gathering it mechanically, lowering costs. The comparison of the costs of establishing the crops (on the basis of 2020 prices) demonstrated that RYE is the most expensive due to the higher seed price of rye, compared with wheat and triticale seed prices. Therefore, costs for WHT and TRT were 19% and 18% less expensive, respectively. Separately, Aasen et al. (2004) assessed the potential of spring cereals under grazing and found a low cost for crop establishment under Canadian conditions.

The best performance of RYE in forage DM yield turned it into the lowest cost forage per each kg DM, decreasing expenditures in comparison with WHT and TRT. Conversely, WHT had the higher feeding cost per kg milk (4.5% and 5.6% v. TRT and RYE, respectively) and a lower income margin in relation to feeding costs

(Table 6); and as has been mentioned, the ratio of income over feeding costs was very favourable since the three treatments were above USD\$ 2.45 income / USD\$ 1.00 feeding costs.

As another advantage of the three cereal grains assessed was their dual purpose possibilities for a silage crop after grazing, as the standing herbage mass at the end of the grazing experiment was 9.9 ton DM/ha for RYE, 5.7 ton DM/ha for TRT, and 4.3 ton/ha for WHT.

Since there were no differences in the animal variables, the three cereals are put forward as viable options for grazing in these small-scale dairy production systems owing to their high DM yields, with adequate protein content and medium digestibility to sustain milk yields and profitability in mid lactation low yielding dairy cows.

## Declarations

### *Funding*

Universidad Autónoma del Estado de México through the grant UAEM 4973/2020CIP and the Mexican National Council for Science and Technology (Consejo Nacional de Ciencia y Tecnología - CONACYT) for the postgraduate grant for Jesús-Israel Vega-García.

### *Conflicts of interest/Competing interests*

The authors declare that they have no conflict of interest.

### *Ethics approval*

Experimental procedures with dairy cows and work with the collaborating farmer followed guidelines accepted by Instituto de Ciencias Agropecuarias y Rurales (ICAR) of Universidad Autónoma del Estado de México, and the experiment was institutionally approved (DICARM-0321).

### *Consent to participate*

The work reported herein was carried out as an on-farm experiment with a collaborating small-scale dairy farmer who was fully aware of the objectives of the work and participated actively in the experiment; was duly informed and consulted and their decisions were respected at all times. Finally, their privacy and that of their family is respected by not disclosing their names.

### *Consent for publication*

Not applicable.

### *Availability of data and material (data transparency)*

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

*Code availability (software application or custom code)*

Not applicable.

*Authors' contributions*

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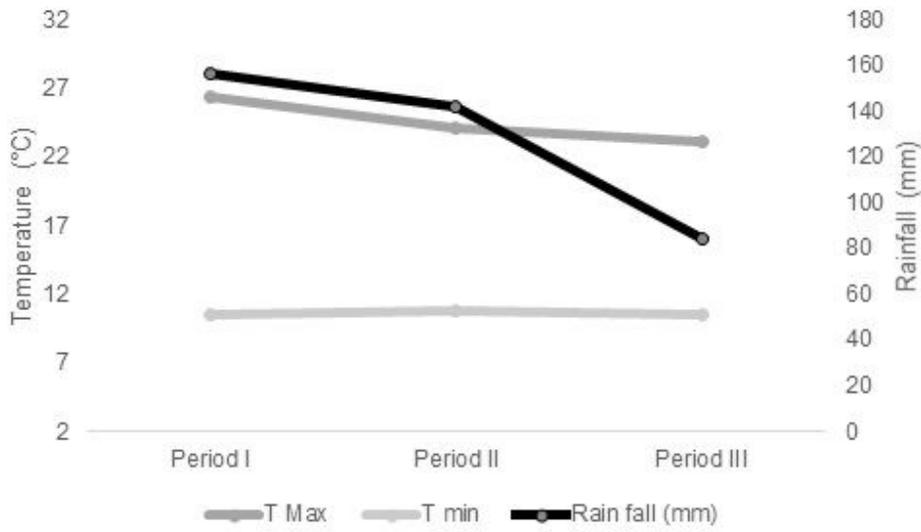
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# Figures



**Figure 1**

Rainfall and mean maximal and minimal temperatures during the Experiment.