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FORAGE YIELD AND COMPOSITION OF BLACK OAT IN MONOCULTURE AND IN ASSOCIATION WITH WINTER VETCH

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ABSTRACT

Associated grass-legume pastures have advantages over grass monoculture; in order to evaluate them the association of black oat (*Avena strigosa* Schreb) with winter vetch (*Vicia villosa* Roth) was analysed. The objective of the study was to evaluate forage yield, the botanical, morphological, and chemical composition of black oat in monoculture and in association with winter vetch, at different crop heights and residual stubble heights. Eighteen treatments were evaluated in randomized complete blocks with divided plots. In large plots, the culture type (monoculture or association); and in small plots, nine harvest management options (combinations) of three crop heights (Ch: 40, 50 and 60 cm) and three residual stubble heights (Rsh: 8, 14 and 20 cm). Forage yield was higher ($p \leq 0.05$) in Ch50-Rsh8, Ch60-Rsh8 and Ch60-Rsh14 during the second crop cycle, with an average 8555 kg DM ha^{-1}. In monoculture and in association, more cuts were made (three to four) with Ch40-Rsh14 and Ch40-Rsh20 and fewer cuts (one to two) with Ch60-Rsh8, Ch60-Rsh14 and Ch60-Rsh20. Crude protein concentration was 19 % higher ($p \leq 0.05$) in monoculture than in association (19.2 and 16.2 %); the highest concentrations ($p \leq 0.05$) of crude protein were obtained in Ch40-Rsh8, Ch40-Rsh14 and Ch40-Rsh20 (average 20.5 %), and the lowest was recorded in Ch60-Rsh8 (13.2 %). The forage with the least neutral detergent fibre ($p \leq 0.05$) was harvested in Ch40-Rsh8, Ch40-Rsh14 and Ch50-Rsh14 (average 43.4 %), and the highest (49.3 %) was obtained in Ch60-Rsh20. In monoculture and in association, a greater amount of forage was harvested, distributed in at least two harvests, with Ch of 50 and 60 cm in combination with 8 and 14 cm of Rsh. However, the forage did not have the best composition, due to higher concentrations of neutral detergent fibre and lower crude protein concentration.

Keywords: *Avena strigosa*, *Vicia villosa*, forage height, harvest intensity.

INTRODUCTION

Associated grass-legume pastures have advantages over grass monoculture, including higher forage yield and protein content (Luscher *et al*., 2014), as in the association of common oats (*Avena sativa* L.) with common vetch (*Vicia sativa* L.) (Erol *et al*., 2009; Flores *et al*., 2016). The advantages of associations are evident with 30 to 50 % legume in the botanical composition (Luscher *et al*., 2014).

Forage production and quality in the associations is also determined by the timing of plant harvest. As oat growth progresses, when plants reach reproductive stages, there is higher dry matter (DM) yield but with lower crude protein (CP) concentration (Espitia *et al*., 2012; Ramírez-Ordóñes *et al*., 2013). In most research on cereals in monoculture and their associations with *Veza* spp. the evaluation of forage yield has focused on a single harvest at the grain filling stage (Ramírez-Ordóñes *et al*., 2013; Flores *et al*., 2016). The reason for a single harvest is due to the increased risk of decapitation of the apical meristem due to the elongation of the grass stems at this phenological stage, which affects regrowth and persistence (Gastal and Lemaire, 2015).

Quiroz-Pérez *et al.* (2016) showed the productive potential of the association of black oat (*Avena strigosa* Schreb) with *Vicia* spp. Black oat or bristle oat stands out for its forage potential (Salgado *et al*., 2013), moreover, when harvested in vegetative stage and at moderate cutting intensities, high quality forage distributed over several harvests can be obtained (Guzatti *et al*., 2015). In Mexico, the cv. Saia is the one recommended (Sánchez *et al*., 2014).

The evaluation of yield and forage quality of black oat, along with its association with common vetch at growth stages, affects nutritional composition of the forage. Thus, it was hypothesized that both from black oat monoculture, and in its association with winter vetch (*Vicia villosa* Roth), high forage yields with better composition distributed over more than one cut can be obtained when harvests are carried out on young plants with moderate cutting intensities. The objective of the study was to evaluate forage yield, the botanical, morphological and chemical composition of black oat in monoculture and in association with winter vetch, at different crop heights and residual stubble heights.

MATERIALS AND METHODS

Location and weather conditions

The research was conducted at the Grazing Module of the Universidad Autónoma Chapingo, Texcoco, Mexico (19° 29′ N, 98° 54′ W, altitude 2240 m) in two crop cycles; the first one from October 2017 to March 2018 and the second one from October 2018 to March 2019. A soil analysis was performed in the experimental area before the study, which resulted in a clay loam texture with pH 7.5; bulk density, 1.04 g cm^{-3}; organic matter, 2.64 %, low in phosphorus (14.1 mg kg^{-1}) and inorganic nitrogen (35.6 mg kg^{-1}). The climate is sub-humid temperate, with summer rains. At the Chapingo meteorological station in the State of Mexico, the average monthly temperature during the first cycle ranged between 11 and 15 °C, and in the second cycle, between 13 and 17 °C. Accumulated precipitation was similar in the two cycles (102 and 110 mm), with no precipitation in December. In November of the second cycle, 12 times more precipitation was recorded than in the first cycle (Figure 1).

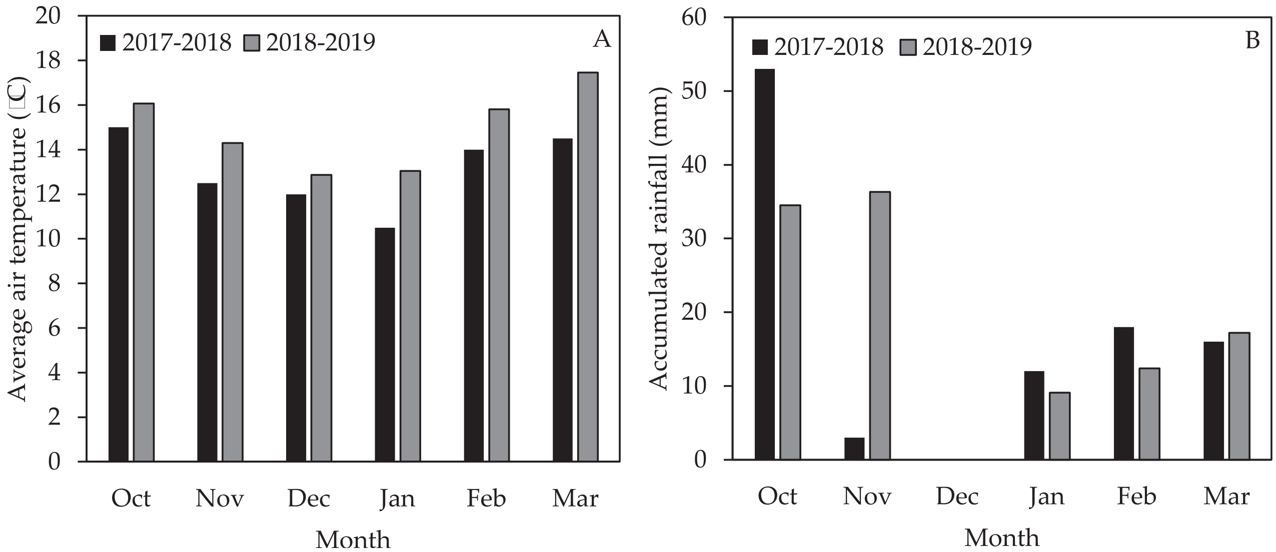

Figure 1. A: monthly average temperature and B: accumulated precipitation during the experimental cycles.

Experimental design and treatments

In a randomized block design with four replications, 18 treatments were evaluated in divided plots. In the large plots, the type of crop was evaluated with two levels, black oat in monoculture and its association with winter vetch. In the small plots, nine harvest management options were evaluated (Table 1) resulting from the combination of three crop heights (Ch, 40, 50 and 60 cm) and three residual stubble heights (Rsh, 8, 14 and 20 cm). The experimental units were 72 plots of 12 m^2 each and 0.5 m wide alleys between plots.

Table 1. Harvest management options evaluated in black oat (*Avena strigosa* Schreb) cv. Saia in monoculture and in association with winter vetch (*Vicia villosa* Roth).

Harvest management options	Ch[†] (cm)	Rsh[¶] (cm)
Ch40-Rsh8	40	8
Ch40-Rsh14	40	14
Ch40-Rsh20	40	20
Ch50-Rsh8	50	8
Ch50-Rsh14	50	14
Ch50-Rsh20	50	20
Ch60-Rsh8	60	8
Ch60-Rsh14	60	14
Ch60-Rsh20	60	20

[†]Ch: crop height; [¶]Rsh: residual stubble height.

Experiment procedures

Sowing date was October 18, 2017 for the first cycle and October 13, 2018 for the second cycle. Seed was sown by hand (on the fly), as well as 130 kg of pure germinal oat seed per hectare in the monoculture; and 100 kg ha^{-1} of black oat seed plus 30 kg ha^{-1} of vetch seed, in the association. At sowing, crop was fertilized with 18 kg N ha^{-1} and 46 kg P_2O_5 ha^{-1}, and 30 kg N ha^{-1} were applied during the tiller stage (an average of three tillers per plant); in addition, 60 kg N ha^{-1} were applied in the monoculture, at first irrigation after each cutting. Every 14 d, on average, sprinkler irrigation was applied (62 mm per irrigation); 13 irrigations were supplied in the first cycle and 11 irrigations in the second cycle.

Crop height records consisted of 15 measurements per plot, using a modified stick with measuring tape. Crop monitoring was done every week, when the average value was close to the defined crop height for each harvest management, records were taken every two days. The average crop heights recorded in the oat monoculture were 41±3, 48±3 and 59±2 cm in the first cycle, and 50±5, 51±4 and 53±8 cm in the second cycle. Whereas, in the association they were 41±3, 50±1 and 60±0 cm in the first cycle, and 40±3, 49±5 and 53±8 cm in the second cycle.

Evaluated variables

The evaluated variables were forage yield (FY, kg DM ha^{-1}), CP concentration (%), neutral detergent fibre (NDF, %), acid detergent fibre (ADF, %), botanical composition of the forage and the morphological composition of the monoculture. The FY was evaluated from the mass of forage harvested with scissors within each plot, at the crop height of each harvest management option, in three fixed sampling units of 0.32 m^2 (0.8 × 0.4 m). The fresh weight of the harvested mass was then recorded. For the determination of DM, an approximate composite sample of 400 g of the forage mass was taken and dried in an oven with forced air circulation at 55 °C, up to constant weight. The FY was evaluated from the sum of the DM yield harvested in each cut of each harvest management option. After cutting the forage samples, in order to maintain the residual stubble heights defined in each harvest management, the total of the remaining forage in each plot was cut with a mower (Model UT44110, Homelite®, USA).

Botanical and morphological compositions were quantified from a subsample composed of 400 g of the forage mass cut in each experimental unit. Black oat, vetch (in association), weeds and dead material were separated manually. The morphological components of oat (leaf blade and pseudostem+stem) were also separated manually and each component was dried until constant weight in a forced-air oven at 100 °C. In the end, the proportion of each component was estimated on a dry weight basis.

Forage chemical composition was evaluated only in the first cycle. For this, the same forage mass samples that were dried (at 55 °C) for DM determination were used and ground in mill (Thomas Model 4, Wiley®, USA), with 1 mm mesh. To estimate CP concentration (N concentration × 6.25), N determinations were made with the Kjeldahl method (Alencar *et al*., 2019). NDF and ADF evaluations were carried out sequentially (Ferreira and Mertens, 2007) with the use of filter bags with porosity of 25 mm (Model F57, Ankom®, USA) in a fibre analyser (Model A200, Ankom®, USA).

Statistical analysis

The evaluated variables were subjected to analysis of variance in SAS®. The model for FY was:

$$Y_{ijkl} = \mu + B_i + C_j + T_k + E_{ijk} + G_l + BT_{ik} + TG_{kl} + CT_{jk} + CG_{jl} + CTG_{jkl} + e_{ijkl}$$

where, Y_{ijkl}, is the dependent variable; μ, the effect of the general mean; B_i, the block effect; C_j the effect of crop cycle; T_k, the effect of crop type; E_{ijk}, the effect of experimental error on larger plot (error a); G_l, the effect of harvest management; BT_{ik}, the effect of the interaction between block and crop type; TG_{kl}, the effect of the interaction between crop type and harvest management option; CT_{jk}, the effect of the interaction between crop cycle and crop type; CG_{jl}, the effect of the interaction between crop cycle and harvest management option; CTG_{jkl}, the effect of the triple interaction between crop cycle, crop type and harvest management option; e_{ijkl}, the effect of the experimental error on smaller plot (error b).

The model for botanical and morphological components was:

$$Y_{ijk} = \mu + B_i + C_j + G_k + CG_{jk} + E_{ijk}$$

where, Y_{ijk}, is the dependent variable; μ, the effect of the general mean; B_i, the block effect; C_j the effect of crop cycle; G_k, the effect of harvest management; CG_{jk}, the effect of the interaction between crop cycle and harvest management; E_{ijk}, the effect of experimental error.

The model for CP, NDF and ADF was:

$$Y_{ijk} = \mu + B_i + T_j + BT_{ij} + E_{ij} + G_k + TG_{jk} + e_{ijk}$$

where, Y_{ijk}, is the dependent variable; μ, the effect of the general mean; B_i, the block effect; T_j, the effect of crop type; BT_{ij}, the effect of the interaction between block and crop type; E_{ijk}, the effect of experimental error in larger plot (error a); G_k, the effect of harvest management; TG_{jk}, the effect of the interaction between crop type and harvest management; e_{ijk}, the effect of experimental error in smaller plot (error b). Means were compared with the test of Tukey ($p \leq 0.05$).

RESULTS AND DISCUSSION

Dates and number of cuts in crops

The number of cuts in the monoculture and in the association varied with every harvest management option (Table 2). Regardless of the type of culture, in Ch40-Rsh14 and Ch40-Rsh20 a higher number of cuts was achieved (three to four), and in Ch60-Rsh8, Ch60-Rsh14 and Ch60-Rsh20 fewer cuts were recorded (one to two). Independently of crop height in the harvest management options, the intervals between cuts in both

Table 2. Cutting dates of black oat (*Avena strigosa* Schreb) cv. Saia in monoculture and in association with winter vetch (*Vicia villosa* Roth) at different harvesting managements, in two crop cycles.

Harvest management options	Ch[†]40 Rsh[¶]8	Ch40 Rsh14	Ch40 Rsh20	Ch50 Rsh8	Ch50 Rsh14	Ch50 Rsh20	Ch60 Rsh8	Ch60 Rsh14	Ch60 Rsh20
Cut	Monoculture in the first crop cycle (2017-2018)								
1	Jan 5	Jan 5	Jan 5	Jan 17	Jan 17	Jan 17	Feb 11	Feb 11	Feb 11
2	Feb 22	Feb 15	Feb 11	Feb 27	Feb 22	Feb 17			Mar 14
3		Mar 7	Feb 27			Mar 14			
4			Mar 17						
das-1[§]	79	79	79	91	91	91	116	116	116
dbc[þ]	48	31	24	41	36	28	-	-	31
Cut	Monoculture in the second crop cycle (2018-2019)								
1	Dec 14	Dec 14	Dec 14	Dec 26	Dec 26	Dec 26	Jan 15	Jan 15	Jan 15
2	Feb 5	Jan 29	Jan 22	Feb 19	Feb 16	Feb 13	Mar 02	Mar 02	Feb 25
3	Mar 4	Feb 25	Feb 13						
			Mar 4						
das-1[§]	62	62	62	74	74	74	94	94	94
dbc[þ]	40	37	27	55	52	49	46	46	41
Cut	Associated crop in the first crop cycle (2017-2018)								
1	Jan 17	Jan 17	Jan 17	Feb 14	Feb 14	Feb 14	Feb 20	Feb 20	Feb 20
2	Feb 27	Feb 20	Feb 17		Mar 13	Mar 7			
3		Mar 13	Mar 7						
das-1[§]	91	91	91	119	119	119	125	125	125
dbc[þ]	41	28	25	-	27	21	-	-	-
Cut	Associated crop in the second crop cycle (2018-2019)								
1	Dec 14	Dec 14	Dec 14	Dec 26	Dec 26	Dec 26	Jan 15	Jan 15	Jan 15
2	Feb 15	Feb 5	Jan 22	Mar 2	Feb 16	Feb 13	Mar 4	Mar 4	Feb 25
3		Feb 28	Feb 13						
			Mar 4						
das-1[§]	62	62	62	74	74	74	94	94	94
dbc[þ]	63	38	27	66	52	49	48	48	41

[†]Ch: crop height (40, 50 and 60 cm); [¶]Rsh: residual stubble height (8, 14 and 20 cm); [§]das-1: days after sowing to first cut; [þ]dbc: days between cuts.

crops were longer with high harvesting intensity (less residual forage, Ch40-Rsh8, Ch50-Rsh8 and Ch60-Rsh8) and shorter with low intensity (more residual forage, Ch40-Rsh20, Ch50-Rsh20 and Ch60-Rsh20).

The increase in the interval between cuts in both crops at higher harvest intensity (less residual forage) is a response that has been observed in grasses. Hamilton *et al*. reported greater interval between cuts when harvesting perennial ryegrass (*Lolium perenne* L.) and fescue (*Festuca arundinacea* Schreb.) at higher harvest intensity (2.5 and 5 cm Rsh) than at lower (12.5 and 15 cm Rsh). This response is related to the slow regrowth of the plants, due to the smaller residual leaf area that remains after intense forage harvest. On the contrary, with low harvesting intensities, the interval between cuts is reduced, due to the rapid growth of the forage originated by the greater residual leaf area in the sprouts that favour photosynthesis (Martins *et al.*, 2021).

In the first crop cycle, the crop height goals at the first cut were reached earlier in the monoculture than in the association; but in the second cycle, the first cut was made on the same date in both crop types. The lower growth of the association compared to monoculture is explained by interspecific competition, which has already been documented in associations of cereals with vetch; as lower growth rates have been observed in associations than in monocultures (Lithourgidis *et al*., 2006).

Forage yield

In the FY, an effect of the crop cycle × crop type × harvest management options interaction was detected ($p \leq 0.001$). However, based on sums of squares, 61 % of the variation was attributed to the crop cycle × harvest management options interaction (38 %, $p \leq 0.05$), and to the effects of crop cycle (18 %, p ≤ 0.05) and crop type (11 %, $p \leq 0.05$) and 14 % to the triple interaction. The highest FYs were obtained in the harvesting managements of Ch50-Rsh8, Ch60-Rsh8 and Ch60-Rsh14 in the second cycle (average 8555 kg DM ha^{-1}). The lowest FYs resulted in Ch50-Rsh8, Ch50-Rsh14, Ch50-Rsh20, Ch60-Rsh8, Ch60-Rsh14 and Ch60-Rsh20 of the first cycle, and with Ch40-Rsh20 and Ch50-Rsh20 of the second cycle (average 5348 kg DM ha^{-1}, Table 3). The FY was 22 % higher ($p \leq 0.05$) in the second cycle than in the first (6866 *vs.* 5632 kg DM ha^{-1}), and 17 % higher ($p \leq 0.05$) in the monoculture than in the association (6743 *vs.* 5754 kg DM ha^{-1}, Figure 2).

The higher FY obtained in Ch50-Rsh8, Ch60-Rsh8 and Ch60-Rsh14 of the second cycle are attributed to the fact that forage was harvested at higher Ch and harvest intensities (lower Rsh) and to the better environmental conditions that were present in the second cycle. There is evidence that FY is higher when harvested at higher heights (Espitia *et al*., 2012) and high intensities (Brink *et al*., 2013; Hamilton *et al*., 2013). In the second cycle, mean monthly temperatures were higher and precipitation one month after sowing (November) was also higher than in the first cycle (Figure 1). This led to the rapid growth and establishment of the crops, and as a result, one more cut was obtained with the harvesting management options (Ch50-Rsh8, Ch60-Rsh8 and Ch60-Rsh14) in the second cycle (Table 2). During the second cycle, even

Table 3. Forage yield of black oat (*Avena strigosa* Schreb) cv. Saia in monoculture and in association with winter vetch (*Vicia villosa* Roth) at different harvesting management options, in two crop cycles.

Harvest management options	Crop cycle	kg DM ha^{-1}
Ch[†]40-Rsh[¶]8	First	5861 cdef
	Second	5882 cdef
Ch40-Rsh14	First	6231 cde
	Second	6072 cdef
Ch40-Rsh20	First	6154 cdef
	Second	5491 def
Ch50-Rsh8	First	5717 def
	Second	7984 ab
Ch50-Rsh14	First	5589 def
	Second	6695 bcd
Ch50-Rsh20	First	5574 def
	Second	4854 f
Ch60-Rsh8	First	5485 def
	Second	8879 a
Ch60-Rsh14	First	4827 f
	Second	8803 a
Ch60-Rsh20	First	5245 ef
	Second	7133 bc
SEM[§]		269
p[Þ]		0.0001

[†]Ch: crop height (40, 50 and 60 cm); [¶]Rsh: residual stubble height (8, 14 and 20 cm); [§]SEM: standard error of the mean; [Þ]*p*: probability of difference; [¤]Means with different letters indicate statistical difference (Tukey, $p \leq 0.05$).

the first cuts in all harvest management options were made on average 19 d earlier in the monoculture and 35 d earlier in the association than during the first cycle (Table 2). As documented in other research conducted in associated crops (Puzynska *et al*., 2021) and monocultures (Solomon *et al*., 2017), it is evident that climatic variations (in temperature and precipitation) between evaluation years affect FY.

The productive advantage of the monoculture versus the association is explained by the fact that in the monoculture there were four more cuts in the first cycle and one more cut in the second cycle than in the association. In this regard, there is evidence that grass forage associated with vetch grows more slowly than when it is grown in monoculture, due to inter-species competition (Lithourgidis *et al*., 2006). As a result, during the first experiment, crop height goals at first cut in the monoculture were reached on average 16 d earlier than in the association (Table 2). Furthermore, in this study, it is likely that the application of N in the monoculture (60 kg N ha^{-1} $harvest^{-1}$) had a greater impact on the FY than in the association.

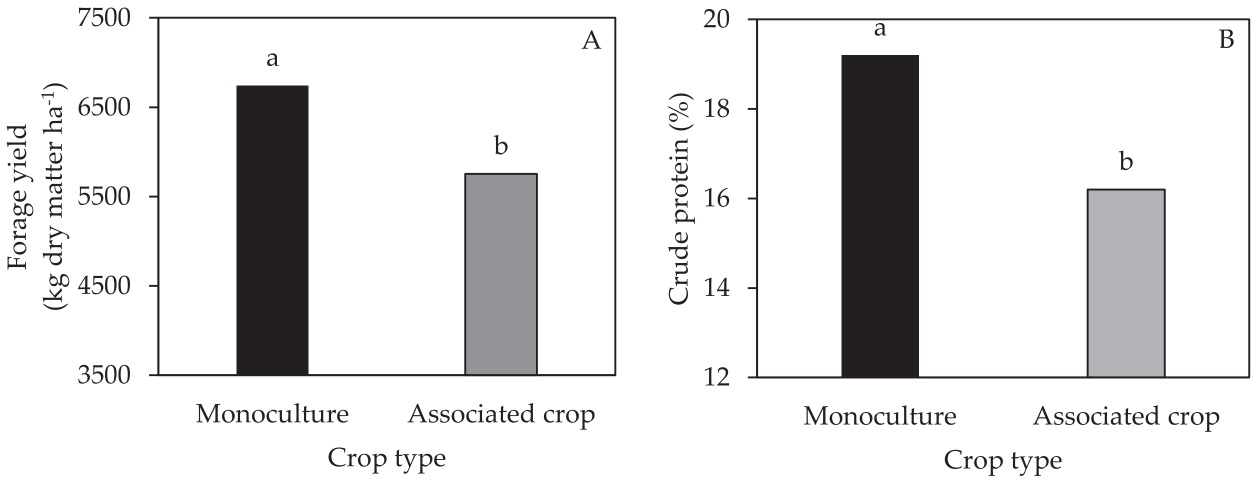

Figure 2. A: forage yield and B: crude protein concentration of black oat (*Avena strigosa* Schreb) cv. Saia in monoculture and in association with winter vetch (*Vicia villosa* Roth). Columns with different letters are different (Tukey, $p \leq 0.05$).

Black oat in monoculture was more productive than their association with winter vetch, which is consistent with other studies (Lithourgidis *et al*., 2006; Tuna and Orak *et al*., 2007), which evaluated the monoculture of common oats and their association with common vetch. On the contrary, Flores *et al*. (2016) mentioned higher FY in the association of common oats with common vetch, but they made a single cut when the grass was in doughy grain and in this study the crop heights were reached in the vegetative stage of oat (the proportion of oat inflorescence was on average 0.6 and 0.7 %).

Botanical and morphological compositions

In monoculture, no effect of the crop cycle × harvest management interaction ($p > 0.05$) was detected on the proportions of oat, weeds, dead material, and oat morphological components (leaf blade, pseudostem+stem and inflorescence). However, there was effect ($p \leq 0.05$) of harvest management options on the proportions of oat, dead material (Table 4) and leaf blade and pseudostem+stem components (Figure 3) In monoculture, the highest proportion of oat resulted in Ch50-Rsh14 (97.7 %) and the lowest in Ch60-Rsh20 (82.9 %). In contrast, dead material content was higher in the harvesting managements with higher crop height Ch60-Rsh8, Ch60-Rsh14 and Ch60-Rsh20 (average 8.7 %), and was lower in Ch40-Rsh8, Ch40-Rsh14, Ch40-Rsh20, Ch50-Rsh8, Ch50-Rsh14 and Ch50-Rsh20 (average 0.5 %, Table 4). The proportion of weeds was similar ($p > 0.05$) in all harvest management options (average 5.3 %).

In monoculture, the highest proportions of oat leaf blade resulted in the Ch40-Rsh14 and Ch40-Rsh20 harvest management options (average 71.5 %), and the lowest in

Table 4. Botanical composition of black oat (*Avena strigosa* Schreb) cv. Saia to different harvest management options, in two crop cycles.

Harvest management options	Black oat	Weeds	Dead material
Ch[†]40-Rsh[¶]8	94.0 ab	6.0	0.0 b
Ch40-Rsh14	89.7 ab	9.6	0.7 b
Ch40-Rsh20	95.2 ab	3.4	1.4 b
Ch50-Rsh8	93.4 ab	6.1	0.5 b
Ch50-Rsh14	97.7a	2.1	0.2 b
Ch50-Rsh20	94.1 ab	5.9	0.0 b
Ch60-Rsh8	88.3 ab	1.0	10.7a
Ch60-Rsh14	88.2 ab	5.2	6.6 ab
Ch60-Rsh20	82.9 b	8.4	8.7a
SEM[§]	2.8	2.3	1.6
p[Þ]	0.007	0.101	0.001
Crop cycle			
First	87.2 b	11.6a	1.2 b
Second	96.3a	0.0 b	3.7a
SEM	1.3	1.1	0.8
p	0.001	0.001	0.025

[†]Ch: crop height (40, 50 and 60 cm); [¶]Rsh: residual stubble height (8, 14 and 20 cm); [§]SEM: standard error of the mean; [Þ]*p*: probability of difference; [¤] Means with different letters between rows indicate statistical difference (Tukey, $p \leq 0.05$).

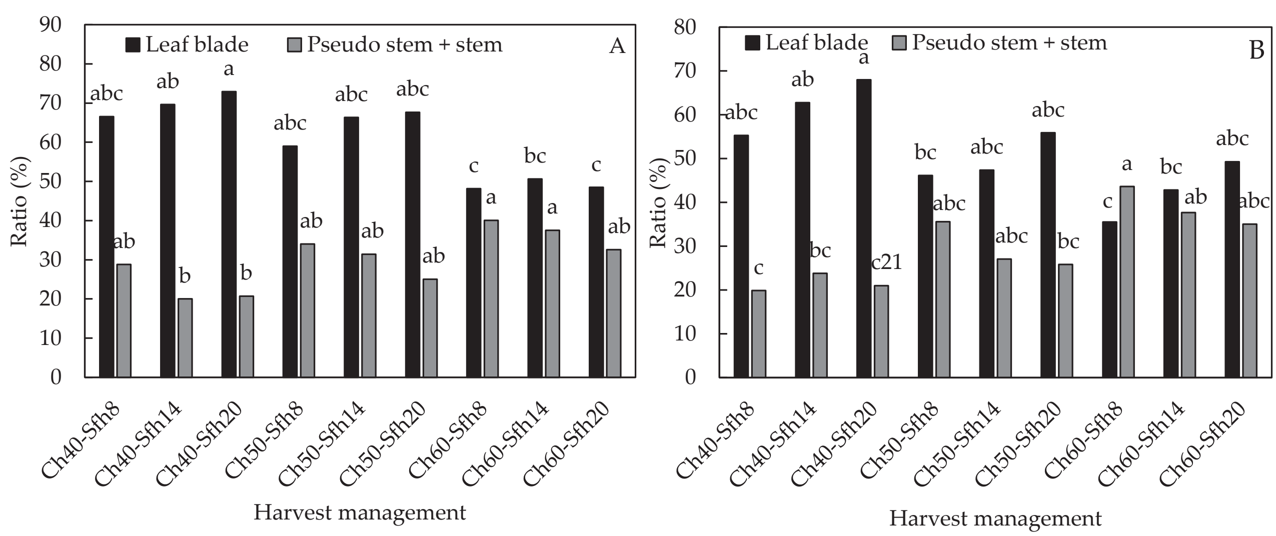

Figure 3. Leaf blade and pseudostem+stem of black oat (*Avena strigosa* Schreb) cv. Saia in A: monoculture and B: in association with winter vetch (*Vicia villosa* Roth) with different harvest management options. Columns with different letters are different (Tukey, $p \leq 0.05$).

Ch60-Rsh8, Ch60-Rsh14 and Ch60-Rsh20 (average 49 %). In contrast, the proportions of pseudostem+stem were lower in Ch40-Rsh14 and Ch40-Rsh20 (average 20.5 %), and higher in Ch60-Rsh8 and Ch60-Rsh14 (average 39 %, Figure 3).

The amount of inflorescence in the harvest management options was similar ($p > 0.05$), on average 0.7 %. Effect ($p \leq 0.05$) of crop cycle on the proportions of oat, weeds and dead material was detected (Table 4). Oat and dead material were 10 and 208 % higher in the second cycle than in the first. Weeds were only present in the first cycle, perhaps due to increased competition from oat in the second cycle.

In the association, an effect of the crop cycle × harvest management options interaction ($p \leq 0.05$) was detected in the proportions of black oat, vetch, and dead material (Table 5). The highest percentages of black oat resulted in Ch40-Rsh14, Ch40-Rsh20, Ch50-Rsh8, Ch50-Rsh14 and Ch50-Rsh20 harvest management options (average 93.9 %), during the second cycle, and the lowest in Ch50-Rsh8, Ch50-Rsh14 and Ch50-Rsh20 from the first cycle (average 61.8 %). The highest proportions of vetch were obtained in Ch40-Rsh8 of the second cycle and Ch50-Rsh14 of the first cycle (average 17.2 %); the

Table 5. Botanical composition of black oat (*Avena strigosa* Schreb) cv. Saia in association with winter vetch (*Vicia villosa* Roth) with different harvest management options, in two crop cycles.

Harvest management options	Crop cycle	Black oat	Vetch	Weeds	Dead material
Ch†40-Rsh¶8	First	73.6 bcd¤	7.9 ab	18.1	0.4 c
	Second	76.7 abcd	17.1a	1.1	5.1 abc
Ch40-Rsh14	First	81.1 abc	7.1 ab	11.0	0.8 c
	Second	93.0 ab	7.0 ab	0.0	0.0 c
Ch40-Rsh20	First	87.1 abc	4.0 b	8.6	0.3 c
	Second	91.7 ab	4.7 b	0.2	3.4 bc
Ch50-Rsh8	First	62.9 cd	10.3 ab	20.0	6.8 abc
	Second	91.1 ab	8.9 ab	0.0	0.0 c
Ch50-Rsh14	First	54.2 d	17.2a	25.2	3.4 bc
	Second	96.5a	3.5 b	0.0	0.0 c
Ch50-Rsh20	First	68.4 cd	10.2 ab	17.1	4.3 abc
	Second	97.2a	2.8 b	0.0	0.0 c
Ch60-Rsh8	First	74.6 abcd	7.9 ab	11.1	6.4 abc
	Second	83.4 abc	4.6 b	0.0	12.0 ab
Ch60-Rsh14	First	80.6 abcd	4.9 ab	10.1	4.3 abc
	Second	80.9 abc	5.2 ab	0.5	13.4a
Ch60-Rsh20	First	83.8 abc	1.8 b	8.1	6.3 abc
	Second	84.5 abcd	4.8 b	0.0	10.7 ab
	SEM§	4.8	2.5	3.8	2.2
	*p*Þ	0.001	0.001	0.261	0.011

†Ch: crop height (40, 50 and 60 cm); ¶Rsh: residual stubble height (8, 14 and 20 cm); §SEM: standard error of the mean; Þ*p*: probability of difference; ¤Means with different letters between rows indicate statistical difference (Tukey, $p \leq 0.05$).

lowest were in Ch40-Rsh20 and Ch60-Rsh20 of the first cycle and Ch40-Rsh20, Ch50-Rsh14, Ch50-Rsh20, Ch60-Rsh8 and Ch60-Rsh20 of the second cycle (average 3.7 %). The highest proportions of dead material were recorded in Ch60-Rsh8, Ch60-Rsh14 and Ch60-Rsh20 of the second cycle (average 12 %), and were null in Ch40-Rsh14, Ch50-Rsh8, Ch50-Rsh14 and Ch50-Rsh20 of the second cycle.

In the association, the highest oat leaf blade proportions resulted in the harvest managements of Ch40-Rsh14 and Ch40-Rsh20 (average 65 %), and the lowest in Ch60-Rsh8 and Ch60-Rsh14 (average 39 %). In contrast, the proportions of pseudostem+stem were lower in Ch40-Rsh8, Ch40-Rsh14, Ch40-Rsh20 and Ch50-Rsh20 (average 23 %), and higher in Ch60-Rsh8 and Ch60-Rsh14 (average 41 %, Figure 3). Oat inflorescence was similar ($p > 0.05$) across harvest management options (mean 0.6 %).

In both monoculture and association, an opposite relationship was detected between leaf blade ratios and pseudostem+stem with increasing crop height in harvest management options; a common relationship that has been observed in forage grasses (Aguinaga *et al*., 2008; Guzatti *et al*., 2015). The leaf blade ratio was higher at 40 cm crop height than at 60 cm, and the pseudostem+stem ratio was higher at 60 cm crop height than at 40 cm. These results are due to the fact that during the growth of grasses there is a modification in their canopy structure. During the vegetative state leaves grow (on stems that do not elongate) and then the state of stem elongation continues (Gastal and Lemaire, 2015; Lemaire and Belanger, 2020), which stops the development of new leaves, so the older leaves are shaded. This process increases senescence and the accumulation of dead material at the base of the canopy (Da Silva *et al*., 2015). This explains why the amount of dead material was higher in the harvest management options with 60 cm of crop height.

In the association, although the proportions of black oat and vetch varied between harvest management options, the proportion of vetch was much lower than that of black oat; on average 81 % black oat and 7 % vetch were harvested. The low proportion of vetch in the association was attributed to the lower proportion of legume seed at planting density; 77 % of seed was black oat and 23 % was vetch. There is evidence that, in the oat-vetch association, the percentage of the legume in the forage harvested reflects the amount of legume seed at seeding density (Erol *et al.*, 2009).

Chemical composition

No effect of crop type × harvest management options interaction ($p > 0.05$) was detected on the chemical composition of forage. The concentration of CP was 19 % higher ($p \leq 0.05$) in monoculture (19.2%) than in association (Figure 2); whereas those of NDF and ADF were similar ($p > 0.05$) between crop types, with averages of 45 and 24 %. The highest CP concentrations ($p \leq 0.05$) were obtained in the harvest management options with the lowest crop height (Ch40-Rsh8, Ch40-Rsh14 and Ch40-Rsh20, average 20.5 %) and the lowest (13.2 %) was recorded with Ch60-Rsh8 (Figure 4). Forage with the lowest NDF concentrations ($p \leq 0.05$) was harvested in Ch40-Rsh8, Ch40-Rsh14 and Ch50-Rsh14 (average 43.4 %), and in Ch60-Rsh20 the forage with the highest NDF

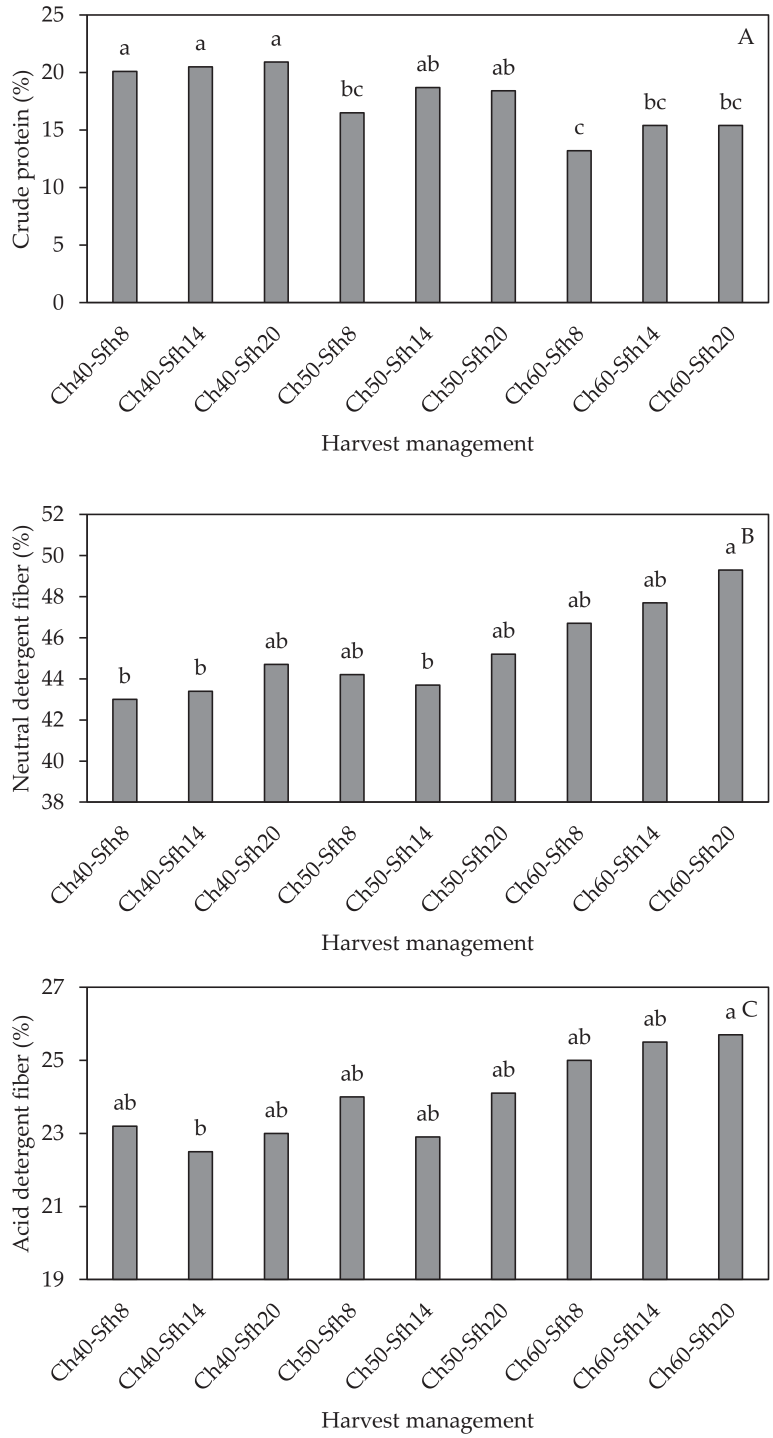

Figure 4. Concentatios of A: crude protein, B: neutral detergent fibre, and C: acid detergent fibre of black oat (*Avena strigosa* Schreb) cv. Saia in monoculture and in association with winter vetch (*Vicia villosa* Roth) with different harvest management options. Columns with different letters in each subfigure are different (Tukey, $p \leq 0.05$).

concentration (49.3 %) was harvested. The concentration of NDF was lowest ($p \leq 0.05$) in Ch40-Rsh14 (22.5 %) and highest in Ch60-Rsh20 (25.7 %).

The lower CP concentration obtained in the grass-legume association of this study does not agree with that mentioned in other research (Lithourgidis *et al*., 2006; Flores *et al*., 2016). This difference is attributed to the effect of oat maturity stage at harvest on forage quality (Molla *et al*., 2018). In this study, the cuts were made when the forage was in vegetative stage, while in studies that have obtained higher CP contribution in the association (Lithourgidis *et al*., 2006, Flores *et al*., 2016) the crop was harvested when the oat were in advanced stages of maturity (reproductive stage) with lower forage quality. Flores *et al.* (2016) obtained CP concentrations of 17.9, 12.5, 9.5, 9.5 and 9.8 % in the blister, milky grain, doughy grain, and mature grain stages; these results are lower than what was obtained in the oat monoculture (19.2 % CP, Figure 2) of this study.

Another reason for the lower CP concentration in the association than in the monoculture was the low proportion of vetch in the botanical composition of the association (1.8 to 17.2 %, Table 5). The CP contribution of mixed grasslands (grass-legume) versus pure grasses are evidently higher when the legume in the composition is in a ratio of 30 to 50 % (Luscher *et al*., 2014). In this study, the vetch seed proportion (23 %) in the association seeding density was lower than that of black oat (77 %). There is evidence that the forage CP of the common oats-common vetch association increases as the percentage of legume at seeding, and within the harvested DM, increases (Erol *et al*., 2009).

The decrease in CP concentration and increase in NDF and ADF concentrations obtained with advancing crop growth are common responses obtained in grasses (Castro-Hernandez *et al*., 2017), legumes (Sulc *et al*., 2020) and oat-vetch associations (Molla *et al*., 2018). With the harvest management options in which a higher proportion of leaf blade was obtained (Ch40-Rsh14 and Ch40-Rsh20) forage was harvested with higher CP concentration and lower NDF and ADF concentrations. On the contrary, with the harvest management options in which the highest proportion of pseudostem+stem was obtained (Ch60-Rsh8 and Ch60-Rsh14), forage was harvested with lower CP concentration and high concentrations of NDF and ADF. This latter is explained by the best chemical composition (less NDF, ADF and more CP) that leaves have compared to stems (Branco *et al*., 2012).

CONCLUSIONS

In black oat in monoculture and in association with winter vetch, more forage was harvested, distributed in at least two cuts, with crop heights of 50 and 60 cm in combination with higher intensity harvests (8 and 14 cm of residual forage). However, the forage harvested with such management options was not the best in composition, due to high proportions of stems, neutral detergent fibre and lower crude protein concentration.

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REFERENCES

Aguinaga AAQ, Carvalho PCF, Anghinoni I, Pilau A, Aguinaga AJQ, Gianluppi GDF. 2008. Componentes morfológicos e produção de forragem de pastagem de aveia e azevém manejada em diferentes alturas. Revista Brasileira de Zootecnia 37 (9): 1523–1530. http://dx.doi.org/10.1590/S1516-35982008000900002

Alencar NM, Vendramini JMB, Dubeux Jr JCB, dos Santos AC, Sánchez JMD, da Silva HM, Silveira ML, Sousa LF, Neiva JNM. 2019. Impact of leaf and stem proportions on dry matter and crude protein *in situ* disappearance of rhizome peanut genotypes. Crop Science 59 (4): 1815–1821. https://doi.org/10.2135/cropsci2019.02.0114

Branco AF, Viana KB, Castañeda RD, Prohmann PE, Coneglian SM, Mouro GF. 2012. Chemical composition and crude protein fractions of Coast cross grass under grazing on winter, spring and summer in Southern Brazil. Acta Scientiarum Animal Science 34 (2): 183–187. https://doi.org/10.4025/actascianimsci.v34i2.10895

Brink GE, Jackson RD, Alber NB. 2013. Residual sward height effects on growth and nutritive value of grazed temperate perennial grasses. Crop Science 53 (5): 2264–2274. https://doi.org/10.2135/cropsci2013.01.0068

Castro-Hernández H, Domínguez-Vara IA, Morales-Almaráz E, Huerta-Bravo M. 2017. Composición química, contenido mineral y digestibilidad *in vitro* de raigrás (*Lolium perenne*) según intervalo de corte y época de crecimiento. Revista Mexicana de Ciencias Pecuarias 8 (2): 201–210. http://dx.doi.org/10.22319/rmcp.v8i2.4445

Da Silva SC, Sbrissia AF, Pereira LET. 2015. Ecophysiology of C_4 forage grasses-understanding plant growth for optimising their use and management. Agriculture 5 (3): 598–625. https://doi.org/10.3390/agriculture5030598

Erol A, Kaplan M, Kizilsimsek M. 2009. Oat (*Avena sativa*)-common vetch (*Vicia sativa*) mixtures grown on a low-input basis for a sustainable agriculture. Tropical Grasslands 43 (3): 191–196.

Espitia Rangel E, Villaseñor Mir HE, Tovar Gómez R, de la O Olán M, Limón Ortega A. 2012. Momento óptimo de corte para rendimiento y calidad de variedades de avena forrajera. Revista Mexicana de Ciencias Agrícolas 3 (4): 771–783. https://doi.org/10.29312/remexca.v3i4.1430

Ferreira G, Mertens DR. 2007. Measuring detergent fiber and insoluble protein in corn silage using crucibles or filter bags. Animal Feed Science and Technology 133 (3–4): 335–340. https://doi.org/10.1016/j.anifeedsci.2006.04.010

Flores N MJ, Sánchez G RA, Echavarría C FG, Gutiérrez L R, Rosales N CA, Salinas G H. 2016. Producción y calidad de forraje en mezclas de veza común con cebada, avena y triticale en cuatro etapas fenológicas. Revista Mexicana de Ciencias Pecuarias 7 (3): 275–291. https://www.scielo.org.mx/pdf/rmcp/v7n3/2448-6698-rmcp-7-03-00275-en.pdf (Retrieved: June 2022).

Gastal F, Lemaire G. 2015. Defoliation, shoot plasticity, sward structure and herbage utilization in pasture: review of the underlying ecophysiological processes. Agriculture 5 (4): 1146–1171. https://doi.org/10.3390/agriculture5041146

Guzatti GC, Duchini PG, Sbrissia AF, Ribeiro-Filho HMN. 2015. Aspectos qualitativos e produção de biomassa em pastos de aveia e azevém cultivados puros ou consorciados e submetidos a pastejo leniente. Arquivo Brasileiro de Medicina Veterinária e Zootecnia 67 (5): 1399–1407. https://doi.org/10.1590/1678-4162-8103

Hamilton SA, Kallenbach RL, Bishop-Hurley GJ, Roberts CA. 2013. Stubble height management changes the productivity of perennial ryegrass and tall fescue pastures. Agronomy Journal 105 (3): 557–562. https://doi.org/10.2134/agronj2012.0293

Lemaire G, Belanger G. 2020. Allometries in plants as drivers of forage nutritive value: a review. Agriculture 10 (1): 5. https://doi.org/10.3390/agriculture10010005

Lithourgidis AS, Vasilakoglou IB, Dhima KV, Dordas CA, Yiakoulaki MD. 2006. Forage yield and quality of common vetch mixtures with oat and triticale in two seeding ratios. Field Crops Research 99 (2–3): 106–113. https://doi.org/10.1016/j.fcr.2006.03.008

Lüscher A, Mueller-Harvey I, Soussana JF, Rees RM, Peyraud JL. 2014. Potential of legume-based grassland-livestock systems in Europe: a review. Grass and Forage Science 69 (2): 206–228. https://doi.org/10.1111/gfs.12124

Martins CDM, Schmitt D, Duchini PG, Miqueloto T, Sbrissia AF. 2021. Defoliation intensity and leaf area index recovery in defoliated swards: implications for forage accumulation. Scientia Agricola 78 (2). http://dx.doi.org/10.1590/1678-992X-2019-0095

Molla EA, Wondimagegn BA, Chekol YM. 2018. Evaluation of biomass yield and nutritional quality of oat–vetch mixtures at different harvesting stage under residual moisture in Fogera District, Ethiopia. Agriculture and Food Security 7: 88. https://doi.org/10.1186/s40066-018-0240-y

Puzynska K, Puzynski S, Synowiec A, Bocianowski J, Lepiarczyk A. 2021. Grain yield and total protein content of organically grown oat–vetch mixtures depending on soil type and oats' cultivar. Agriculture 11 (1): 79. https://doi.org/10.3390/agriculture11010079

Quiroz-Pérez JC, Améndola-Massiotti RD, Zaragoza-Ramírez JL, Ortiz-Moreno O. 2016. Consumo aparente de forraje de *Avena strigosa* y *Vicia* spp. con riego, bajo pastoreo invernal en el centro de México (PP116. Producción y utilización de pasturas). Revista Argentina de Producción Animal 36 (Supl.1): 410. https://www.aapa.org.ar/rapa/36/Vol36Supl1.pdf (Retrieved: September 2022).

Ramírez-Ordóñes S, Domínguez-Díaz D, Salmerón-Zamora JJ, Villalobos-Villalobos G, Ortega-Gutiérrez JA. 2013. Producción y calidad del forraje de variedades de avena en función del sistema de siembra y de la etapa de madurez al corte. Revista Fitotecnia Mexicana 36 (4): 395–403. https://revistafitotecniamexicana.org/documentos/36-4/4r.pdf (Retrieved: May 2022).

Salgado P, Thang VQ, Thu TV, Trach NX, Cuong VC, Lecomte P, Richard D. 2013. Oats (*Avena strigosa*) as winter forage for dairy cows in Vietnam: an on-farm study. Tropical Animal Health and Production 45: 561–568. https://doi.org/10.1007/s11250-012-0260-8

Sánchez Gutiérrez RA, Gutiérrez B H, Serna P A, Gutiérrez L R, Espinoza C A. 2014. Producción y calidad de forraje de variedades de avena en condiciones de temporal en Zacatecas, México. Revista Mexicana de Ciencias Pecuarias 5 (2): 131–142.

Solomon JKQ, Macoon B, Lang DJ. 2017. Harvest management based on leaf stage of a tetraploid *vs*. a diploid cultivar of annual ryegrass. Grass and Forage Science 72 (4): 743–756. https://doi.org/10.1111/gfs.12313

Sulc RM, Arnold AM, Cassida KA, Albrecht KA, Hall MH, Min D, Xu X, Undersander DJ, van Santen E. 2020. Changes in forage nutritive value of reduced-lignin alfalfa during regrowth. Crop Science 61 (2): 1478–1487. https://doi.org/10.1002/csc2.20366

Tuna C, Orak A. 2007. The role of intercropping on yield potential of common vetch (*Vicia sativa* L.)/oat (*Avena sativa* L.) cultivated in pure stand and mixtures. Journal of Agricultural and Biological Science 2 (2): 14–19.