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Yields and chemical composition of different parts of the common vetch at flowering and at two seed filling stages

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Abstract

In annual forage legumes such as the common vetch (*Vicia sativa* L.), in which the pods represent a substantial proportion of the total biomass, the optimum harvesting stage may not adjust to the classical model of decreasing nutritive value after flowering. The effect of harvest time on the yield of the main chemical components of common vetch was evaluated under field conditions typical of the Castilian Plain (Mediterranean continental-type climate under rain-fed conditions). Over two growing seasons (1996-1997 and 1997-1998), plants were harvested at flowering and at two stages during seed filling (characterized by a progressively higher dry matter content of the seed; 280 and 380 g kg^{-1} respectively). The results show that the greater quality and quantity of the pods offsets the decrease in quality occasioned by the aging of the vegetative plant parts (stems plus leaves). Crude protein yields were not affected by delaying the harvest-time. Starch yields were higher when the plant was harvested during seed-filling. Sugar yields increased between flowering and seed filling in the first growing season but decreased in the second. Yields of structural components such as neutral-detergent fibre, acid-detergent fibre and acid-detergent cellulose, followed a pattern similar to that of crude protein. There therefore appears to be a flexible harvest period ranging from flowering until the beginning of seed filling (seeds with 380 g dry matter kg^{-1}), which may be advantageous when trying to select optimum haymaking conditions.

Key words: *Vicia sativa,* harvesting time, protein yield, fibre content.

Resumen

Rendimientos y composición química de los componentes morfológicos de veza común en dos estados de madurez de la semilla

En leguminosas forrajeras anuales como la veza común (*Vicia sativa* L.), en las que la legumbre representa una proporción considerable de la biomasa total, el momento óptimo de corte puede no ajustarse al modelo clásico de disminución del valor nutritivo después de la floración. En este trabajo se evaluó el efecto del momento de recolección de la veza común sobre el rendimiento de los principales constituyentes químicos en condiciones de secano típicas de la Meseta Castellana. Las plantas se cosecharon durante dos años consecutivos (1996-1997 y 1997-1998), en floración y en dos estados de madurez de la legumbre (materia seca de la semilla 280 y 380 g kg^{-1}, respectivamente). Los resultados mostraron que, al avanzar la madurez, la mayor calidad y cantidad de la legumbre contrarresta la disminución de la calidad de las partes vegetativas de la planta. Los rendimientos de proteína bruta no se vieron afectados por un retraso en la fecha de recolección. Los de almidón, sin embargo, fueron mayores al estado de legumbre madura, y los de azúcares aumentaron desde la floración al estado de legumbre en el primer año, mientras que disminuyeron en el segundo año. Los rendimientos de constituyentes estructurales (fibra neutro-detergente, fibra ácido-detergente y celulosa ácido-detergente) siguieron una tendencia similar a los de la proteína bruta. Se concluye que existe un margen de maniobra entre la floración y las primeras fases de formación de la semilla (semilla con 380 g de materia seca kg^{-1}) que permite elegir las mejores condiciones de henificación.

Palabras clave: *Vicia sativa,* estado de corte, rendimiento en proteína, contenido en fibra.

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Introduction

Common vetch (*Vicia sativa* L.) is an annual legume cultivated under rain-fed conditions in the semi-arid regions of Spain and other Mediterranean countries. In these areas, vetch is integrated into the conventional cereal-fallow crop rotation system. This species helps alleviate seasonal forage deficits and therefore contributes to the economic sustainability of cereal-sheep farming systems (Caballero, 1999). Moreover, this leguminous crop provides soil cover during the rainy season, fixes atmospheric nitrogen, increases soil organic matter and breaks pest, disease and weed cycles (Lacasta, 1995; ICARDA, 1998).

In the mixed cereal and sheep production systems of the Castilian Plain, complementary vetch forage provides the bulk of the protein in sheep rations. Common vetch is harvested as hay in May-June and used to meet the winter-time forage deficit. Previous studies have illustrated the lack of quality standards for on-farm hays (Caballero *et al.*, 1996a). Two main factors causing hay quality variation have been identified. The first, seeding rate, was addressed in a previous paper (Caballero *et al.*, 1995); the second, harvesting time, is dealt with in the present paper.

Unlike in other leguminous forage crops such as alfalfa (*Medicago sativa* L.) or different types of clover (*Trifolium spp*.), common vetch pods account for a high proportion of the total plant biomass (Caballero *et al.*, 1996b). The conventional model of decreasing quality of biomass after flowering may not be applicable to common vetch forage. We hypothesized an offsetting effect of the pods on the decreasing quality of the vegetative plant parts (stems plus leaves) after flowering.

The aim of the present study was to investigate how delaying harvesting beyond flowering and into the seed-filling phase affects the chemical composition and yield of common vetch forage. Quantitative data were collected to assess the forage quality of common vetch for use in animal feeding systems.

Material and Methods[1]

Experimental design, cultivation and sampling

Field studies were conducted at La Poveda Field Station (30 km southeast of Madrid) during the 1996-97 and 1997-98 growing seasons. Vetch was planted and cultivated under rain-fed conditions. The area is subject to the continental Mediterranean climatic conditions of the Castilian Plain (altitude = 610 m; 30 year mean precipitation = 425 mm; mean number of days with frost = 40); its soil was an alluvial sandy loam (Typic Xerofluvent); pH = 7.7 (H_2O), organic matter = 17 g kg^{-1}, C/N ratio = 7.9, N = 1.3 g kg^{-1}, $CaCO_3$ = 42 g kg^{-1}, available P = 90 mg kg^{-1} (Burriel and Hernández, 1950), available K = 120 mg kg^{-1} (MAPA, 1986).

The rainfall recorded during the three months before harvest was 1.5, 35.4 and 33.5 mm for March, April and May in 1997, and 19.2, 33.9 and 76.0 mm for the same months in 1998. The corresponding average mean temperatures were 13.8, 15.5 and 16.7ºC for 1997 and 12.7, 11.9 and 14.3ºC for 1998.

Common vetch cv. Vereda was sown on November 27th 1996 and November 25th 1997 at a seeding rate of 80 kg ha^{-1} in rows 0.17 m apart. Before sowing, the experimental area was fertilized with 24.4 kg P ha^{-1} and 23.2 kg K ha^{-1} using a compound fertilizer (N-0, P-6.1, K-5.8). Linuron [N'- (3,4-dichlorophenyl)-N-methoxy-N-methylurea] (0.875 kg ha^{-1}) was applied for pre-emergence weed control. Vetch forage was harvested at three stages: at flowering (F) (more than 50% of plants with flowers), and at two seed filling stages defined by a progressively higher seed dry matter (DM) content (means of 280 and 380 g DM kg^{-1} for seed filling stages 1 and 2 [SF1 and SF2] respectively). More advanced growth stages were not studied since vetch reaches full pod growth before 500 g DM kg^{-1} seed is attained (Caballero, 1989; Caballero *et al.*, 1996b).

Harvesting stage treatments were allocated following a completely randomised design with three replications in single plots measuring 4 × 20 m. Forage yields were determined by harvesting a 1.5 × 10 m area in the centre

[1] *Abbreviations:* ADC: acid detergent cellulose. ADF: acid detergent fibre. ADL: acid detergent lignin. CP: crude protein. DM: dry matter. F: flowering; HS: harvesting stage. INDF: indigestible neutral detergent fibre. NDF: neutral detergent fibre. NS: non significant. SE: standard error of the means. SF1: seed filling stage 1. SF2: seed filling stage 2. WP: whole plant. WP-P: whole plant minus pods.

of the plots. All plants were cut approximately 5 cm above the level of the soil with a scythe.

Plants assigned to the flowering stage were harvested on May 28th 1997 and May 8th 1998. Twenty individual plants were randomly selected from each single plot and separated into leaves and stems. The dry matter contents of fresh whole forage and plant parts were determined by oven-drying at 60ºC for 22 h and subsequently at 80ºC for 2 h. Mean leaf to stem ratios were calculated.

Plots assigned to SF1 and SF2 were harvested on the 12th and 21st June 1997 and on the 20th May and 4th June 1998 respectively. In all cases, 30 randomly selected plants from single plots were separated into leaves, stems and pods. Whole fresh forage and plant part samples were oven-dried as described above.

Approximately 3 kg of fresh forage were randomly collected from each plot at the two seed-filling stages and the vegetative parts (stems plus leaves) and pods separated by hand. Samples for chemical analyses were placed in freezer bags, frozen at –20ºC, freeze-dried and milled to pass a 1 mm screen. Samples of the whole plant at the flowering stage were similarly treated.

Chemical analyses

Dry matter (DM) and crude protein (CP) contents were determined by standard methods (AOAC, 1995). The starch content was determined from the amount of glucose released after its gelatinisation and enzymatic hydrolysis by amyloglycosidase (EC 3.2.1.3; Boehringer), as described by Longstaff and McNab (1991). The sugar content was determined by extraction with aqueous ethanol (80%, v v^{-1}) and colorimetric analysis following the anthrone method (Yemm and Willis, 1954). Neutral-detergent fibre (NDF) was analysed according to Van Soest *et al*. (1991) using a heat-stable α-amylase (Termamyl 120, Novo, Denmark). Acid-detergent fibre (ADF), acid-detergent cellulose (ADC) and acid-detergent lignin (ADL) were determined by the method of Goering and Van Soest (1970), as modified by Robertson and Van Soest (1981).

Yields and statistical analyses

Chemical component yields for the whole plant were calculated as the product of the DM yield of the plant and the concentration of the corresponding chemical components (also in terms of DM).

The variables analysed statistically were the content in CP, starch, sugar and cell-wall components (NDF, ADF, ADC, and ADL), and the yields of these chemical components. A two-factorial fixed effects model including interactions ($Y_{ij} = \mu + A_i + B_j + AB_{ij} + \varepsilon_{ij}$, where i = 1,2,3 and j = 1,2) was used to examine the chemical component content. The main effects were harvesting stage (A) and plant parts (B). The mean squares of the main effects, and those of the interaction, were compared to that of the residual. Analyses of variance were performed by year since differences between years were detected, as shown by *year × treatment* interactions and the heterogeneity of the error. The 2V program of the BMDP statistical package was used (BMDP, 1992).

Values for indigestible neutral detergent fibre (INDF) were estimated using linear (Chandler, 1980) and non-linear log-log (Traxler *et al*., 1998) equations, and expressed as percentages of neutral detergent fibre.

Results

Yields of whole plant and morphological parts

Table 1 shows the dry matter yields for the whole plant and the proportion of its morphological parts (leaves, stems and pods). Overall mean whole plant yields of 5,730 and 8,501 kg DM ha^{-1} were recorded in the first and second season respectively. Mean leaf to stem ratios at the flowering stage (in terms of DM) were 1.64 and 1.23 in 1997 and 1998 respectively. Table 1 shows that the relative proportion of vegetative parts (leaves plus stems) decreased from SF1 to SF2, this effect being less intense in the first (160 g kg^{-1}) than in the second growing season (254 g kg^{-1}). The relative contribution of pods was much higher in the second than in the first season at both seed filling stages studied. The annual mean DM content of fresh whole forage was 173 g kg^{-1}.

Chemical components

Table 2 shows the chemical composition of the whole plant and its vegetative parts at the three

Table 1. Whole plant and morphological part (leaves, stems and pods) yields of common vetch at the three harvesting stages

	1996-1997					1997-1998				
	Harvesting stage			SE	P value	Harvesting stage			SE	P value
	F	SF1	SF2			F	SF1	SF2		
Whole plant (kg ha^{-1} on DM)	5,450^a	6,041^a	5,698^a	254.9	0.3268	7,853^a	9,357^a	8,294^a	464.6	0.1408
Morphological parts (g kg^{-1}on DM)										
— Leaves	621^a	430^b	315^c	8.3	0.0000	552^a	315^b	214^c	8.7	0.0000
— Stems	379^a	421^b	376^a	9.9	0.0296	448^a	345^b	192^c	15.3	0.0001
— Pods	—	149^a	309^b	7.8	0.0000	—	340^a	594^b	14.0	0.0000

F: flowering; SF1: 280 g DM kg^{-1} seed; SF2: 380 g DM kg^{-1} seed. For each growing season, values in a row followed by the same letter are not significantly different.

harvesting stages studied. The CP content decreased significantly ($P<0.001$) over the two growing seasons as maturity increased, with mean differences of 30.4 and 69.4 g kg^{-1} DM in WP and WP-P respectively from F to SF2. As expected, the CP content of the pods (Table 3) was higher than that of the whole plant and its vegetative parts, but remained almost unchanged over the two pod maturation stages studied. Significant differences ($P < 0.001$) were also found in the CP contents of the different plant parts (Table 2). The vegetative parts showed a lower CP content than the whole plant at both seed filling stages and in both growing seasons (the mean differences were 26.7 g kg^{-1} DM at SF1 and 39.0 g kg^{-1} DM at SF2). The rate of decrease of the CP content of the vegetative plant parts was more pronounced in the first (F-SF1) than in the second interval (SF1-SF2), with values of 3.78 and 1.70 g CP kg^{-1} DM day^{-1} respectively. The CP content

Table 2. Chemical composition of common vetch forage (whole plant and vegetative parts) at the three harvesting stages (g kg^{-1} DM)

	Harvesting stage					SE	Significance		HS×PP
	F	SF1		SF2					
	WP	WP	WP-P	WP	WP-P		HS	PP	
1996-1997									
Crude protein	221.0	200.8	170.8	189.2	151.2	4.25	***	***	*
Starch	14.5	40.3	21.7	99.1	53.6	4.70	***	**	*
Sugars	88.1	117.0	121.9	116.9	143.9	4.87	***	NS	NS
NDF	344.3	358.4	390.6	362.6	404.5	5.11	*	**	*
ADF	264.1	260.8	284.2	257.5	286.4	4.50	NS	**	NS
ADC	212.7	205.2	228.2	197.6	223.3	3.04	NS	***	*
ADL	46.9	55.9	62.2	60.7	66.5	1.32	***	*	NS
1997-1998									
Crude protein	198.2	173.5	150.1	169.1	129.2	1.97	***	***	***
Starch	39.9	128.6	103.2	167.0	72.9	4.43	***	***	***
Sugars	139.6	104.4	106.3	94.6	114.3	3.98	***	NS	NS
NDF	345.7	338.4	380.6	324.3	394.3	4.63	NS	***	***
ADF	250.6	236.3	268.6	221.5	272.8	3.71	NS	***	**
ADC	199.7	188.6	209.8	173.9	208.5	3.71	NS	**	*
ADL	54.3	55.0	62.7	50.0	65.3	1.24	NS	***	**

F: flowering. SF1: 280 g DM kg^{-1} seed. SF2: 380 g DM kg^{-1} seed. HS: harvesting stage effect. PP: plant part effect. HS × PP = Interaction effect. *** $P < 0.001$. ** $P < 0.01$. * $P < 0.05$.

Table 3. Chemical composition of common vetch pods at two harvesting stages (g kg^{-1} DM)

	Harvesting stage		SE	Significance
	SF1	SF2		
1996-1997				
Crude protein	282.0	279.8	14.17	NS
Starch	170.1	230.0	2.25	***
Sugars	107.1	91.7	4.69	NS
NDF	211.8	198.8	13.75	NS
ADF	118.3	116.8	8.52	NS
ADC	97.3	99.3	6.87	NS
ADL	26.1	22.9	1.71	NS
1997-1998				
Crude protein	221.9	210.9	2.40	*
Starch	165.6	243.2	11.19	**
Sugars	107.5	98.9	4.84	NS
NDF	263.8	220.6	4.65	**
ADF	155.6	134.9	1.76	**
ADC	129.8	110.5	1.92	**
ADL	33.6	27.3	1.25	*

SF1: 280 g DM kg^{-1} seed. SF2: 380 g DM kg^{-1} seed. *** P<0.001. ** P<0.01. * P<0.05.

reduction rate of the whole plant was much lower than that of its vegetative parts (1.75 and 0.63 g CP kg^{-1} DM day^{-1} in the first and in the second interval respectively).

Table 2 shows the non-structural carbohydrate contents (starch and sugars) for the whole plant and its vegetative parts. The starch content of the whole plant showed an analogous pattern in both seasons, increasing significantly ($P < 0.001$) at a similar rate in both intervals as maturity advanced: 4.4 and 4.1 g kg^{-1} DM day^{-1} at F-SF1 and SF1-SF2 respectively. Across maturity stages, the starch content was significantly different in the two growing seasons, the maximum content for the whole plant being reached at SF2 (99.1 and 167.0 g kg^{-1} DM in the first and second season respectively). During the first growing season, the sugar content increased ($P < 0.001$) between F and SF1 but remained unchanged from SF1 to SF2; it decreased ($P < 0.001$), however, between flowering and SF1 in the second season. With respect to the pods, Table 3 shows there were significant differences ($P < 0.01$) in starch content between the two seed filling stages (greater at SF2 than at SF1 in both seasons). On the contrary, the sugar content was not affected by seed maturity. With respect to cell-wall components (Table 2), the data for each plant part were analysed separately since the interaction *harvesting stage x plant part* was significant (due at least in part to the different trends observed in the WP and WP-P results, especially in the second season). Across seasons and harvesting stages, the vegetative parts showed a significantly ($P < 0.05$) greater proportion of structural components than the whole plant (mean differences: 46.6, 34.0, 26.1 and 8.8 g kg^{-1} DM for NDF, ADF, ADC and ADL respectively). For the vegetative parts, NDF, ADF and ADL contents increased from flowering to seed filling in both growing seasons. In the whole plant, however, the NDF content remained unchanged with advancing maturity in both seasons. The ADF and ADC content did not change in the first season and decreased in the second. The lignin (ADL) content of the whole plant increased from F to SF in the first season but remained unchanged in the second. In the pods (Table 3), the cell-wall components remained approximately unchanged in the first season but decreased significantly ($P < 0.05$) in the second. The higher seed proportion with increasing maturity (149 and 340 g kg^{-1} at SF1, and 309 and 594 g kg^{-1} at SF2, in the first and second seasons respectively) (Table 1) might balance out the progressively higher content in structural components of the vegetative parts, counteracting the effect of maturity on the whole plant fibre content (with the exception of ADL in the first season) (Table 2).

Figure 1 shows the estimated values for indigestible neutral detergent fibre (INDF), expressed as a

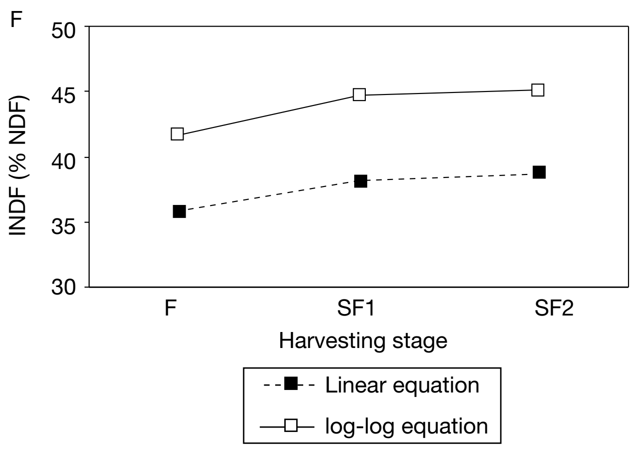

Figure 1. Changes in indigestible neutral detergent fibre in whole common vetch plants, estimated by linear (Chandler, 1980) and non-linear log-log (Traxler *et al.,* 1998) equations. SF1: 280 g DM kg^{-1} seed. SF2: 380 g DM kg^{-1} seed.

percentage of NDF. The INDF content of the whole plant (mean of two seasons) increased from flowering to seed filling (35.8 ± 1.00 and 41.7 ± 0.25 at F, 38.2 ± 1.08 and 44.7 ± 0.27 at SF1, and 38.6 ± 1.09 and 45.1 ± 0.27 at SF2 for linear and non-linear equations respectively).

Yields of chemical components

Table 4 shows the whole plant chemical component yields. Besides the diminishing trend in the CP content mentioned above, CP yields were not significantly affected by maturity. For the three harvesting stages of the two study years, the overall mean value was 1,347 kg ha^{-1}. Yields of non-structural carbohydrates, however, were significantly affected by plant maturity. Across seasons, the highest whole plant starch yield was obtained at SF2 (mean 975 kg ha^{-1}). This can be attributed to the accumulation of starch in the seeds at this stage. Sugar yields increased from F to SF in the first season, and decreased at SF2 in the second season. In both seasons, the yields of most fibre components showed a similar pattern. The NDF, ADF and ADC yields were not significantly affected by maturity, whereas ADL yield increased from F to SF in the first season.

Large differences between the two growing seasons were found in the yields of chemical components. Thus, across harvesting stages, the yields reached in the second season were higher than those attained in the first (Table 4), the relative differences being 31% for CP, 327% for starch, 54% for sugars and 35-44% for all cell-wall components.

Discussion

The mean whole plant DM yield in the second growing season was 2,772 kg ha^{-1} greater than in the first (Table 1). Dry matter yields of common vetch and other annual legumes in this semi-arid environment are highly correlated to the quantity and distribution of rainfall during the months (March-April-May) prior to harvesting (Caballero, 1984). In the present study, the rainfall recorded for this period was 70.4 and 129 mm in 1997 and 1998 respectively. In addition, in the second growing season, the rainfall was more evenly distributed; in the first growing season most fell near flowering and had less influence on yield.

The whole plant CP content at flowering (mean = 209.6 g kg^{-1} DM; Table 2) was in the range of values reported in crop maturity studies performed by Thomson *et al*. (1990). The reduction in whole plant CP content from F to SF2 was 30.4 g kg^{-1} DM; a similar reduction was found by the above authors between early flowering stage and the late flowering-early pod stage. The general trend towards a lower CP content with increasing maturity was more evident in the vegetative parts than in the whole plant, the rate of CP reduction being higher in the first interval (F-SF1) than in the second (SF1-SF2).

Pod CP (Table 3) showed an overall mean value of 248.7 g kg^{-1} DM - 98.5 g kg^{-1} higher than that of the vegetative parts. In contrast with the variation in CP observed in the vegetative parts (Table 2), pod CP changed only slightly between the two reproductive stages studied. This might be explained by the fact that during the period of rapid seed growth (SF1 to SF2), most of the CP accumulated in the grain had been

Table 4. Chemical component yields of whole common vetch at the three harvesting stages (kg ha^{-1} on DM)

	1996-1997					1997-1998				
	Harvesting stage			SE	P value	Harvesting stage			SE	P value
	F	SF1	SF2			F	SF1	SF2		
Crude protein	1,204^a	1,213^a	1,080^a	74.2	0.4152	1,557^a	1,623^a	1,403^a	84.6	0.2717
Starch	79^a	243^b	565^c	18.8	0.0000	313^a	1,203^b	1,385^b	54.1	0.0001
Sugars	480^a	707^b	666^b	27.0	0.0022	1,089^a	977^a	785^b	54.3	0.0107
NDF	1,876^a	2,166^a	2,071^a	103.4	0.2021	2,722^a	3,169^a	2,690^a	194.5	0.2300
ADF	1,439^a	1,575^a	1,467^a	66.4	0.3713	1,975^a	2,212^a	1,837^a	139.6	0.3713
ADC	1,159^a	1,240^a	1,126^a	52.1	0.3495	1,576^a	1,766^a	1,442^a	74.8	0.2210
ADL	256^a	338^b	346^b	14.1	0.0071	428^a	514^a	415^a	30.9	0.1218

SF1: 280 g DM kg^{-1} seed. SF2: 380 g DM kg^{-1} seed. For each growing season, values in a row followed by the same letter are not significantly different.

redistributed from the vegetative to the reproductive structures (Caballero *et al*., 1998). The results of the present study also suggested a trade-off between the decreasing CP content of the vegetative parts and the increasing pod content (mean pod contribution to total harvested forage was 245 and 452 g kg^{-1} DM at SF1 and SF2 respectively) (Table 1). Haj Ayed *et al*. (2001) reported a similar effect in samples of common vetch and hairy vetch field-cured hays.

The non-structural carbohydrate results (Table 2) show the combined effect of morphological changes and of photosynthetic activity between flowering and SF2. As expected, a trend towards a higher whole plant starch content was seen with advancing maturity in both growing seasons. This is attributable to the combination of an increasing contribution of the seed to whole plant values (Table 1) and the accumulation of this carbohydrate in the seed during pod development (Table 3). Nevertheless, a greater starch content did not correlate with a proportional decrease in sugars (Table 2); this agrees with the results of earlier work (Caballero *et al*., 1998). In the latter paper, we indicated that most of the starch was derived from photosynthesis and not from sugar redistribution. Although starch and sugars represent the main digestible carbohydrate fractions, their ruminal degradation rates are very different. While sugars are rapidly fermented, starch must be hydrolysed to simple sugars before fermentation. The proportion of rapidly fermented carbohydrates relative to degradable CP in the rumen can affect the efficiency of microbial protein synthesis and CP utilisation (Gill, 1990).

An offsetting effect for the structural carbohydrate content of the whole plant was also observed. The trend towards higher contents in the vegetative parts of the plant with maturity (Table 2) was compensated by the greater contribution of the seed to the whole plant DM yield (Table 1). These results are in agreement with those of Thomson *et al*. (1990), who reported that the modified acid detergent content of vetch forage did not change between the early flowering stage and the late flowering-early pod stage.

In forages such as vetch, the energy supplied to ruminants by structural carbohydrates is related to the degree of NDF digestion. It is generally accepted that lignin is the primary entity in reducing the proportion of potentially digestible fibre. The estimated INDF values (Fig. 1), based on the lignin and NDF contents, increased from flowering to SF1 and remained almost unchanged during the two seed filling stages studied, regardless of the equation (linear or non-linear) used for predicting the amount of unavailable fibre. The present results also illustrate that the log-log equation used to estimate the energy content of the vetch gave a lower value than the linear equation, although it is unclear which has the best predictive power. Traxler *et al*. (1998) reported that both equations under-predicted actual cattle weight gains (the log-log equation to a greater extent), since the higher the INDF content, the lower the forage energy value.

During the two growing seasons studied, whole plant CP yields (Table 4) were not affected by maturity and showed an overall mean value of 1,166 and 1,528 kg CP ha^{-1} in the first and second seasons respectively. These values are higher than those reported by Moreira (1989) for hairy vetch (*Vicia villosa* Roth.) (799-1,204 kg CP ha^{-1}) cultivated in northeastern Portugal, and by Piñeiro *et al*. (2002) for common vetch cv. Jaga (832-952 kg CP ha^{-1}) in northwestern Spain. No harvesting stage effect was seen on structural carbohydrate yields; a significant effect was seen, however, on ADL and non-structural carbohydrate yields (Table 4). This contrasting behaviour might be explained by the combined effects of plant composition (in terms of chemical components) and the partitioning changes that occur. Hintz and Albrecht (1994) reported that maturity at harvest had the greatest effect on DM partitioning and chemical composition in soybean (*Glycine max* (L.) Merr) plant parts. In common vetch and soybean, the seed fraction accounts for a considerable proportion of the harvested biomass, and contributes substantially to the total yields of the most valuable chemical components. The relative contribution of the pods to whole plant yields in this study at SF1 and SF2 (mean of two seasons) were 32% and 60% for CP, 53% and 79% for starch, and 24% and 43% for sugars.

In conclusion, the DM and CP yields of common vetch depend more on the year and less on the growth stage at harvest (between flowering and SF2). In this period, a compensatory effect between the decay of the vegetative parts and seed development is seen. Growth stage, however, has a significant effect on non-structural carbohydrate yields. This pattern does not agree with the conventional model for other forage legumes, such as alfalfa, in which harvesting after flowering involves a loss of energy and protein biomass. This harvest flexibility of common vetch may be an advantage when trying to determine the optimum haymaking conditions between flowering and seed-filling (the latter corresponding to a seed DM content of 380 g kg^{-1} , i.e., close to full pod growth but before the seed starts to change colour).

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References

AOAC, 1995. Official methods of analysis (Kunniff P., ed). Association of Official Analytical Chemists International. Arlington, VA.

BMDP, 1992. Statistical Software Inc. University of California Press. Los Angeles, CA.

BURRIEL F., HERNÁNDEZ V., 1950. El fósforo en los suelos españoles. Nuevo método para determinar el fósforo asimilable. An Edaf Agrob 9, 611-622.

CABALLERO R., 1984. Los sistemas agrícolas en Castilla-La Mancha y el lugar de la producción forrajero pratense. Proc. II Jornadas Ganaderas de Castilla-La Mancha. Diputación Provincial de Guadalajara-SINA, Guadalajara, Spain, December 12-14. pp. 205-251.

CABALLERO R., 1989. Yields and chemical composition of whole-crop field beans and their components during pod-filling. Grass Forage Sci 44, 347-351.

CABALLERO R., 1999. Castile-La Mancha: A once traditional and integrated cereal-sheep farming system under change. Am J Alter Agr 14, 188-192.

CABALLERO R., GOICOECHEA E.L., HERNAIZ P.J., 1995. Forage yields and quality of common vetch and oat sown at varying seeding ratios and seeding rate of vetch. Field Crop Res 41, 135-140.

CABALLERO R., REBOLÉ A., BARRO C., ALZUETA C., TREVIÑO J., 1996a. Farming practices and chemical bases for a proposed quality standard of vetch-cereal hays. Field Crop Res 47, 181-189.

CABALLERO R., BARRO C., REBOLÉ A., ARAUZO M., HERNAIZ P.J., 1996b. Yield components and forage quality of common vetch during pod filling. Agron J 88, 797-800.

CABALLERO R., REBOLÉ A., BARRO C., ALZUETA C., ORTIZ L.T., 1998. Aboveground carbohydrate and nitrogen partitioning in common vetch during seed filling. Agron J 90, 97-102.

CHANDLER J.A., 1980. Predicting methane fermentation biodegradability. Masters Thesis, Cornell Univ, Ithaca, NY.

GILL M., 1990. Problemas en el ensilado de la hierba y sus posibles soluciones. Proc. XXX Reunión Científica de la SEEP, San Sebastián, Spain, June 4-8. pp. 127-133

GOERING H.K., VAN SOEST P.J., 1970. Forage fiber analyses. USDA, Agriculture Handbook No 379. US Government Printing Office. Washington, DC.

HAJ AYED M., GONZÁLEZ J., CABALLERO R., ALVIR M.R., 2001. Effects of maturity on nutritive value of field-cured hays from common vetch and hairy vetch. Anim Res 50, 31-42.

HINTZ R.W., ALBRECHT K.A., 1994. Dry matter partitioning and forage nutritive value of soybean plant components. Agron J 86, 59-62.

ICARDA, 1998. Annual Report (1997) International Center for Agricultural Research in the Dry Areas, Aleppo, Syria.

LACASTA C., 1995. Investigaciones sobre el secano en Castilla-La Mancha. Spanish Council for Scientific Research (CSIC). Madrid.

LONGSTAFF M.A., MCNAB J.M., 1991. The effect of concentration of tannin-rich bean hulls (*Vicia faba* L.) on activities of lipase (EC 3.1.1.3) and α-amylase (EC 3.2.1.1) in digesta and pancreas and on the digestion of lipid and starch by young chicks. Brit J Nutr 66, 139-147.

MAPA, 1986. Métodos oficiales de análisis. Publication Service, Ministry of Agriculture, Fisheries and Food, Madrid, Spain, Tomo III.

MOREIRA N., 1989. The effect of seed rate and nitrogen fertilizer on the yield and nutritive value of oat-vetch mixtures. J Agr Sci Camb 112, 57-66.

PIÑEIRO J., SAU F., CASTRO P., 2002. Effect of relative seeding rates of oats (*Avena sativa* L.) and common vetch (*Vicia sativa* L.) on total and harvested yield and crude protein content. Grass Sci Eur 7, 466-467.

ROBERTSON J.B., VAN SOEST P.J., 1981. The detergent system of analysis and its application to human food. In: The analysis of dietary fibre in foods (James W.P.T., Theander O., eds). Ed Marcel Dekker, NY. pp. 123-158.

THOMSON E.F., RIHAWI S., NERSOYAN N., 1990. Nutritive value and yields of some forage legumes and barley harvested as immature herbage, hay and straw in North-West Syria. Exper Agr 26, 49-56.

TRAXLER M.J., FOX D.G., VAN SOEST P.J., PELL A.N., LASCANO C.E., LANNA D.P.D., MOORE J.E., LANA R.P., VÉLEZ M., FLORES A., 1998. Predicting forage indigestible NDF from lignin concentration. J Anim Sci 76, 1469-1480.

VAN SOEST P.J., ROBERTSON J.B., LEWIS B.A., 1991. Methods for dietary fibre, neutral detergent fibre, and non-starch polysaccharides in relation to animal nutrition. J Dairy Sci 74, 3583-3597.

YEMM E.W., WILLIS A.U., 1954. The estimation of carbohydrates in plant extracts by anthrone. Biochem J 57, 508-514.