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in

Dubeuf J.-P. (ed.).
L'évolution des systèmes de production ovine et caprine : avenir des systèmes extensifs face aux changements de la société

Zaragoza : CIHEAM
Options Méditerranéennes : Série A. Séminaires Méditerranéens; n. 61

2004
pages 153-160

A system analysis of the interaction between wheat crop management and sheep grazing in aftermath stubble

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SUMMARY – No-till management of rainfed wheat is gaining popularity in semi-arid Mediterranean regions subsequent to improved water utilization, relative to the traditional wheat sowing following soil-discing. However, it is generally associated with straw mulching of the soil, which excludes straw-baling and stubble grazing by sheep. In the Northern Negev of Israel (250 mm of rainfall), during three years of drought (193, 207, 173 mm of rainfall), the yield of wheat grain was increased more than 40% by no-till management, but straw mulching had no additive effect. During a "favorable year" (284 mm of rainfall), no effects on grain yield and quality were found for no-till or straw mulching. Dry Awassi ewes consumed daily 1 kg of wheat stubble, less than their requirement for maintenance. Energy expenditure, measured by the heart rate method, was 20% higher in sheep grazing stubble than those fed an iso-energetic diet distributed indoors. Stubble grazing was economically profitable to both wheat growers and sheep-breeders.

Key words: Semi-arid environment, pasture, energy expenditure, Mediterranean production systems.

RESUME – *"Analyse systémique de l'interaction entre la gestion d'une culture de blé et le pâturage de moutons dans des chaumes après la moisson". On sème de plus en plus le blé sans labour dans les régions semi-arides de la Méditerranée car cela améliore l'utilisation de l'eau. Cette pratique est associée en général avec le recouvrement du sol avec la paille, ce qui exclut la récolte de la paille et le pâturage des chaumes par les ovins. Nous avons montré que dans le Nord du Néguev en Israël (250 mm de précipitations) la culture du blé sans labour permettait d'augmenter de 40% la récolte de grain pendant 3 ans de sècheresse (193, 207 et 173 mm de pluie), mais que le recouvrement du sol avec de la paille n'avait pas d'effet additif. Pendant une année favorable (284 mm de pluie), ni le semis sans labour ni le recouvrement du sol n'ont affecté la récolte de grains ou leur qualité. Des brebis Awassi taries ont consommé 1 kg de chaumes par jour, sans couvrir leurs besoins d'entretien. Leur dépense d'énergie aux chaumes, mesurée d'après le rythme cardiaque, a excédé de 20% celle associée à la consommation d'une ration iso-énergétique à la bergerie. Le pâturage des chaumes était économiquement profitable autant aux céréaliers qu'aux bergers.*

Mots-clés : *Environnement semi-aride, pâturage, dépense d'énergie, systèmes de production Méditerranéens.*

Introduction

In drought-prone areas, the conventional approach is the employ a wheat-fallow rotation system, where water availability is increased through the storaqe of water in the absence of crop growth during the fallow year (Bonfil *et al.*, 1999). Fallow improves soil sanitation (Amir and Sinclair, 1996), but it represents an underutilization of the land resource, contradictory with the requirements of an ever-increasing population at the Southern and Eastern shores of the Mediterranean basin. Soil mulching with straw has also been shown a simple way to reduce soil water evaporation (Bonfil *et al.*, 1999) and improve soil sanitation (Amir and Sinclair, 1996), resulting in increased grain yield in drought years, but not in all years of good rainfall. Following twenty-five years of experimentation, no-till management of continuous wheat (without fallow), associated with straw mulching of the soil, is considered a sustainable system even in areas where rainfall does not exceed 250 mm (Bonfil *et al.*, 1999).

Sheep-breeding is traditionally associated with small grain farming in Mediterranean areas. Sheep are traditionally grazed on fallow fields and wheat stubble represents an important fodder for sheep in the summer (Landau *et al.*, 2000). Although sheep grazing may not be not contradictory to no-till management, it is certainly so to straw mulching, because only 1000 kg/ha of stubble is left on the soil following sheep grazing (Guessous *et al.*, 1991), whereas a straw cover of 4000 kg/ha has been claimed a minimum to ensure the benefits of mulching (Amir and Sinclair, 1996). According to data recorded in 78 farms in Southern Israel, grain represents 31-35% of the total accumulated in the wheat crop (Zaban, 1981). In other words, the maximal yearly amount of straw that is available to mulch the soil in semi-arid areas in the Northern Negev of Israel, where yearly rainfall averages 250 mm and the continuous grain yield amounts to less than 1500 kg/ha, is approximately 3000 kg/ha. The amount of mulched straw soil cover needed to maximize grain yield has not been quantified. In addition, because of the rainfall variation, the straw cover has been shown to fluctuate and straw has been arbitrarily added to cover the soil following a drought year (Amir and Sinclair, 1996). No quantitative investigation of the role of straw mulch effect on continuous wheat grain production under no-till management in this region has been reported, to our knowledge. Therefore, even though there is no evidence that grazing in wheat stubble is deleterious to continuous wheat production under no-till management, sheep flocks may, in the future, be denied access to stubble, in order to prevent straw mulch depletion.

The nutritional quality of stubble is low, owing to low nitrogen content and digestibility (Landau *et al.*, 2000). Sheep are grazed on wheat stubble after grain is harvested, from June to September, under harsh ecological conditions of dustiness, high temperature and with no shade. An experiment carried out on German Merino ewes showed that grazing at that time was associated with 70% higher energy requirement for maintenance (Benjamin *et al.*, 1977). Therefore, the profitability of grazing sheep on wheat stubble, from the point of view of sheepherders, is questionable, compared with the alternative of feeding sheep indoors.

The aim of this study was: (i) to evaluate the effect of stubble-grazing by sheep on the yield and quality of wheat grain under no-till management and its effect on profitability for wheat growers; (ii) to evaluate the nutritional contribution of wheat stubble grazing for sheep and its profitability to sheep-breeders; and (iii) gather information from all actors in order to build-up a model of stubble utilization.

Materials and methods

Location and climate

A five-year study was carried out at the Migda Experimental Farm (34º25"E, 31º22"N) in the Northern Negev of Israel. The soil at Migda is a deep sandy loam loess-Calcic Xerosol mantle, with a water storage capacity of 150 mm/m of soil. The climate is Mediterranean, featuring no rain before November or after the beginning of April. The long-term average rainfall (Fig. 1) is 243 mm. Four years (1997, 1998, 1999, 2000) were drought years (193, 207, 76, 173 mm of rainfall, respectively), but only in 1999 wheat could not be harvested. "More than statistically normal" precipitation occurred for only one year (284 mm, 2001). In 1998, high temperatures affected the crop at the time of grain-filling.

Wheat management

Twelve plots of 0.8 ha each were used for experiment. These plots had been submitted to traditional continuous wheat cultivation, featuring discing, N and P fertilization according to expected grain yield (taking into account their soil concentration), straw baling and sheep grazing in stubble. From Mid-November 1996, they were switched to no-till management, featuring simultaneous hydraulic pulse sowing at a rate of 300 seeds/m^2 and fertilizing. At Harvest (end of May), the combine was equipped with a straw chopper. In the first year, mechanical straw mulching was implemented. Plots were allotted to 4 treatments: 3000 kg/ha of straw cover, 1500 kg/ha of straw cover, or mechanical removal of wheat biomass following the harvest of grain. Three adjacent commercial fields served as controls. From the second year onward, when it appeared that the highest level of straw mulch could not be maintained without artificial addition of straw, treatments were no-till and mulching (n = 6), no-till and mechanical removal of residue (n = 3), and no-till and grazing (n = 3). In order to improve the comparison between no-till and traditional (disced) management of wheat, two 20 m wide strips were disced within each treatment to serve as internal controls (Fig. 2). Soil cover with mulched straw was assessed before sowing, using 6 quadrates of 0.5 m^2 per plot from 1997 to 2000. Wheat biomass accumulation, grain yield and quality [crude protein (CP) and test weight, assessed by the weight of 100 litres of grain] were yearly recorded. Stubble particles were visually classified as grain, delicate (generally leaves) or coarse constituents (generally stems).

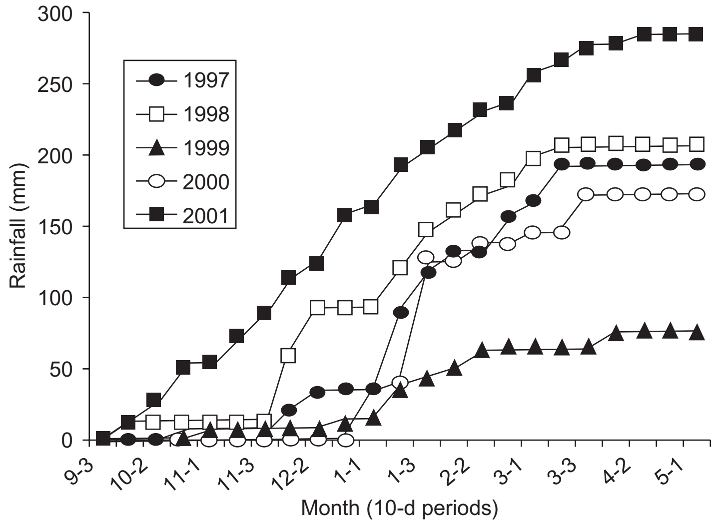

Fig. 1. Ten-day interval rainfall accumulation at Migda during the study.

		Straw mulching				Mechanical removal		
		Mechanical removal				Straw mulching		
		Grazing				Grazing		
		Mechanical removal				Straw mulching		
		Straw mulching				Straw mulching		
		Straw mulching				Grazing		

Fig. 2. Experimental design of wheat plots: the shaded areas represent disced areas, whereas non-shaded plots are under no-till management.

Animals

Dry Awassi ewes were grazed in fenced fields, from 06:00 to approx. 10:00 and from 16:00 to 19:30, using the traditional method, in which grazing is interrupted when ewes cease to graze and aggregate so as to decrease body surface and to cool their heads. Between the grazing sessions, they rested in the shade and were watered in an enclosure located 300 m from the stubble plots. No water was available at pasture.

Assessing wheat stubble intake

Intake at pasture was established for at least 5 grazing days every year. This was done by using a modification of the procedure described by Penning and Hooper (1985) based on weighing sheep before and after grazing with an allowance for insensible weight loss (IWL), as described by Barkai *et al.* (2002).

Seven sheep were fit with harnesses in which feces and urine were collected in disposable diapers. Live-weight was estimated using an electronic balance equipped with software including an algorithm devised to weigh animals with an accuracy of ±10 g (Merav 2002, Shekel balances, Rosh Haain, Israel). Once the animal stepped on the scale, weighing was operated automatically 30 times per second and digits were displayed when the S.E. of weight values reached ±10 g, i.e. the accuracy of the scale. Evaluation of IWL was measured individually in muzzled ewes for 30 minutes before and after each grazing session. Qualitative intake of grain, delicate and coarse constituents of stubble was assessed by subtracting the composition of stubble in five quadrates of 0.5 x 0.6 m in each plot, before and after each grazing day. This enabled us to formulate a diet, fed indoors, iso-energetic to grazed stubble, in compare the energetic cost of grazing stubble with that of eating an iso-energetic diet fed indoors in 2000.

Assessing energy expenditure

Energy expenditure was assessed on four animals in 2000, as described by Barkai *et al.* (2002). Energy expenditure was calculated from oxygen consumption, assuming that 20.47 kJ of energy expenditure corresponds to the utilization of 1 litre of O_2. Oxygen consumption throughout the day was estimated as the product of heart beats by O_2 pulse, the amount of oxygen delivered to body tissues at each heart beat. This was done by fitting the animals with external electrodes and data loggers (Dansoft, Rehovot, Israel) that were permanently fitted to the animals. Heart rate was measured four times for 10 s every 20 min and replicate values were averaged. The consumption of oxygen was measured on two occasions, while grazing stubble and indoors, simultaneously with heart rate (to make sure that measuring O_2 pulse is not associated with elevated heart rate), in order to quantify O_2 pulse. High heat load reduce O_2 pulse in sheep (Barkai *et al.*, 2002; Brosh *et al.*, unpublished). Therefore, skin temperature was logged continuously in order to identify hours at which heat load might have reduced O_2 pulse. Energy expenditure was then calculated accordingly.

Statistics

The effects of tillage, straw mulching, removal method (grazing or mechanical) and year were examined in the 5-year data by analyses of variance as main treatments. The effects of grazing stubble vs feeding indoors on heart rate and energy expenditure was assessed, using a repeated measurement procedure, with sheep (treatment) as the term of error (SAS, 1989).

Results and discussion

Wheat

Wheat was harvested every year, at the exception of 1999 (76 mm of rainfall), when total wheat biomass was only 150 kg/ha. This year was excluded from the statistical analysis.

Straw mulch cover

The soil cover of was affected ($P < 0.0001$) by treatment (mulching, grazing or mechanical removal), and tended to be decrease by year in mulched fields ($P = 0.08$) where no removal of biomass (mechanical or by grazing) took place (Table 1). This partly results of the extreme drought in 1999. In addition, it seems that weathering, including the effects of wind, microbial decomposition and predators (mainly ants and rodents) make it difficult to keep a steady (close to 3000 kg/ha) soil cover. No attempt was made to add exogenous straw in order to reach the initial amount mulched straw. Consequently, the categories of soil cover for statistical analyses were changed to "less than 1000", "1000-2400" and "greater than 2400" kg/ha. Residues left after grazing and mechanical removal did not differ statistically.

Wheat yield and quality

Wheat yield was increased by more than 40% by no-till ($P < 0.01$), compared with the traditional management that included discing, at drought years, but not in a favorable year (Table 2). Before 1999, under no-till management, the effect of straw-mulching on grain yield was slightly positive (13%, 1997, $P < 0.05$) or quadratic (Table 2), including some negative effect for medium soil cover on grain filling, as evidenced lower test weight. The effects of grazing, mechanical removal, and mulching, on subsequent wheat yield, can truly be compared only for three years, i.e. 1998, 2000 and 2001, because all fields were grazed before implementation of extraneous straw mulch in 1996, and no wheat was harvested in 1999. Only fields with highest initial soil cover more than 2400 kg/ha from 1997 were included in the statistical analysis. Straw mulching had no effect on wheat grain yield but tended to be associated with greater total accumulation of wheat biomass, lower percentage of grain and lower test weight, compared with grazing ($P < 0.10$). It seems that straw mulching encouraged vegetative growth, causing water shortage condition at the grain-filling stage if mulching was less than maximal. The effect of grazing on subsequent wheat yield did not differ from that of mechanical removal (Table 3).

Table 1. Straw mulch (kg/ha) prior to sowing (means ± SE)

Treatment	Autumn 1997 after drought	Autumn 1998†† after drought	Autumn 1999†† after extreme drought	Autumn 2000††† favorable
Straw mulching†	^{A}2581 ± 167	^{A}2155 ± 440^{a}	^{B}1075 ± 170^{a}	^{B}1043 ± 152^{a}
Mechanical removal	475 ± 85	280 ± 15^{b}	270 ± 100^{b}	527 ± 214^{b}
Grazing	1043 ± 390	923 ± 270^{ab}	323 ± 73^{b}	703 ± 205^{b}

†Row-wise, means of straw-mulch with different superscripts (uppercase) differ at $P < 0.05$.
††Column-wise, means with different superscripts (lowercase) differ at $P < 0.05$.
†††Column-wise, means with different superscripts (lowercase) differ at $P < 0.10$.

Table 2. Grain yield (kg/ha) and quality, as assessed by CP content and test weight

	No-till and straw mulching			Traditional (disced)
Mulch amount (kg/ha)	Less than 1000	1000-2400	Greater than 2400	
Year				
1997				
Grain yield	1020^{b}	1100^{ab}	1170^{a}	670^{c}
CP content (%)	9.9	10.8	10.2	n.d.†††
1998				
Grain yield†	1030^{ab}	830^{b}	1080^{a}	510^{c}
CP content (%)††	10.0^{b}	11.3^{a}	10.0^{b}	n.d.
100 litres weight	74.6^{a}	71.9^{b}	73.4^{ab}	n.d.
Mulch amount (kg/ha)	Less than 1000	Greater than 1000		
2000				
Grain yield††	970^{a}	1010^{a}		607^{b}
CP content	16.2	17.0		17.3
100 litres weight	77.7	77.7		77.4
2001				
Grain yield	1510	1520		1440
CP content	11.3	11.7		12.7
100 litres weight	76.6	73.9		72.1

†Within years, treatment means with different superscripts differ at $P < 0.10$.
††Within years, treatment means with different superscripts differ at $P < 0.05$.
†††n.d.: no data.

Overall, our findings are consequent with those by Amir and Sinclair (1996) and Bonfil *et al.* (1999) that no-till management increases grain yield in drought, but not in all favorable years. We are not aware of attempts to identify separately the effects of no-tillage and straw mulching. The lack of effect of mulch in the present study, contradictory to others carried out in less flat areas (Bonfil *et al.*, unpublished), is consequent with the finding that soil cover as few as 1000 kg/ha is needed to prevent water erosion as shown also in the Great Plains (Anonymous, 1999), and that water runoff events are rare in Migda. To summarize, it appeared that the dramatic effect on wheat yield resulted from the sowing method, and not from straw mulching.

Table 3. The effects of grazing, mechanical removal and straw-mulching (initially 3000 kg/ha) on the subsequent yield (kg/ha) and quality of wheat grain in 1998, 2000 and 2001 under no-till management of wheat (means ± SE)

	Straw-mulching	Grazing	Mechanical removal	Main effects		
				Year	Treatment	Year × treatment
Total biomass production	3930 ± 150	3380 ± 212	3654 ± 212	0.01	n.s.[†]	n.s.
Grain yield	1136 ± 55	1165 ± 78	1182 ± 78	0.001	n.s.	n.s.
Grain percent in biomass	28.9 ± 1.5[b]	34.7 ± 2.1[a]	32.6 ± 2.1[ab]	0.003	0.10	n.s.
CP (%)	12.6 ± 0.29	12.2 ± 0.40	12.6 ± 0.40	0.0001	n.s.	n.s.
Volumetric weight (kg/100 litres)	74.3 ± 0.6[b]	76.7 ± 0.8[a]	75.8 ± 0.8[ab]	0.01	0.07	n.s.

[†]n.s.: not significant.
[a,b]Treatment means with different superscripts differ at $P < 0.10$.

Stubble grazing

Feed intake in wheat stubble

The daily intake of dry matter (DM) from wheat stubble averaged 1 kg (Table 4), i.e. comparable, on live-weight basis, to that of dry Comisana ewes grazing barley stubble under similar climatic condition (Avondo *et al.*, 2000).

Table 4. Maximal temperature (Tmax, ºC), insensible weight loss (g/h) and the dry matter intake (DMI, g/d) of dry Awassi ewes in stubble: means ± SE

	Conditions	Tmax (°C)	Insensible weight loss			DMI
			Before 08:00	09:30-12:00	17:00-20:00	
August 1998	New stubble[†]	34	169 ± 64	341 ± 97	255 ± 79	1142 ± 172
September 1998	Depleted stubble[†]	33	404 ± 80	401 ± 38	320 ± 50	712 ± 209
September 1999	New stubble[†]	32	n.d.[††]	236 ± 23	281 ± 103	854 ± 128
September 1999	New stubble	32	101 ± 20	412 ± 52	125 ± 52	1283 ± 153
July 2000	New stubble	36	309 ± 40	291 ± 23	220 ± 56	772 ± 196
July 2000	New stubble	40	181 ± 14	340 ± 12	172 ± 15	1000 ± 76
July 2000	New stubble	38	193 ± 12	284 ± 12	161 ± 11	900 ± 104
July 2000	New stubble	35	169 ± 15	284 ± 17	88 ± 29	1260 ± 119

[†]Supplementation, 300 g of a commercial concentrate.
[††]n.d.: no data.

It is important to note that the irreversible weight loss in the present study reached 400 g/h. This enabled to reduce the fast periods to 0.5 h, but inaccuracies in weighing or recording correct individual weighing times could bias the results. In 2000, live-weight decreased from 60.8 to 58.1 kg within 5 days of stubble grazing without supplementation.

Energy expenditure in sheep grazing stubble

Before grazing, grain represented 2% of biomass, while delicate and coarse constituents represented 42.1 and 55.9% of wheat biomass, respectively. Delicate constituents had markedly higher CP content (3.1 vs 1.7%) and *in vitro* digestibility (56.6 vs 41.7%) than coarse constituents.

Based on changes in fixed quadrates in the fields before and after grazing sessions, it appeared that the disappeared material featured 51.1% DM digestibility, 3.7% CP, with approximately 5% of grain. A diet consisting of 50 g wheat grain, 640 g of straw and 400 g of wheat hay served as iso-energetic to the stubble diet, to be fed indoors. The bi-modal pattern of heart rate (Fig. 3) could be explained by the grazing schedule, with significantly higher rate during grazing, compared with rest hours (P = 0.01). When kept indoors, sheep had a mono-modal pattern of heart rate. Heart rate values during measurement of O_2 pulse did not differ from daily averages logged from the same animals while grazing freely (Table 5). The elevation of heart rate at pasture tended to be compensated by lower O_2 pulse (13%, P = 0.15, Table 5). Energy expenditure was approximately 20% higher at stubble than indoors, i.e. much lower than reported before by Benjamin *et al.* (1977) for Merino ewes fed outside without shade. All ewes were in negative energy balance, as expected (Avondo *et al.*, 2000).

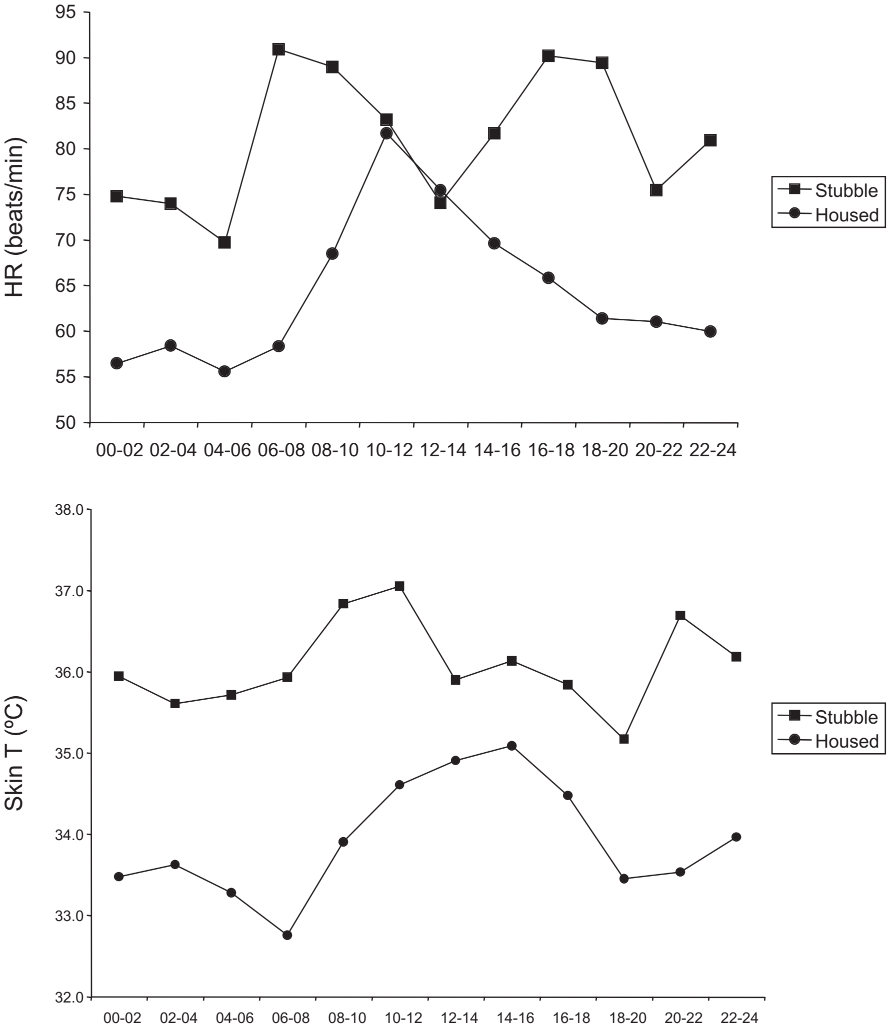

Fig. 3. Diurnal heat rate (HR, beats/min) and skin temperature (ºC) in sheep feeding on wheat stubble (■) or fed indoors an iso-energetic diet (●).

Table 5. Mean daily heart rate (HR, beats/min), O_2 pulse (ml/kg $LW^{0.75}$/d), intake of metabolizable energy (MEI, MJ/d) and energy expenditure (EE, MJ/d) in sheep grazing stubble or fed an iso-energetic diet indoors (n = 4)

	HR		O_2 pulse††	MEI	EE††
	Ordinary†	During O_2 pulse†			
Stubble	81.1^a	79.2^a	0.21^a	6.6	13.7
Indoors	66.4^b	58.2^b	0.26^b	6.7	10.8

†Means with different superscripts row-wise differ at P < 0.1.

††Means with different superscripts row-wise differ at P < 0.05.

Conclusion: Raw economic analysis

Simple calculations were carried out, taking into account the market prices of wheat grain and wheat straw (150 and 40 USD/ton, respectively), costs of discing or no-till managements, the cost of hiring stubble (35 USD/ha, corrected for 20% increment of energy requirement) and the cost of purchasing feeds which nutritional value that is similar to stubble (63 and 104 USD/ton in drought and favorable years, respectively). Under economic conditions prevalent in semi-arid regions in Israel, no-till management of the wheat crop that includes straw baling and/or grazing of wheat stubble following harvest, seems to be more profitable to wheat growers than the traditional management or than a no-till and straw mulching system that excludes baling and grazing. Stubble grazing was profitable to sheep-breeders at all years. Grazing has also sociological and cultural advantages for the Bedouins herders that cannot easily be quantified.

To conclude, it seems that no-till management of wheat, including grazing is a sound and integrated production system for semi-arid lands at the fringe of the desert.

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