Ann Zootech (1994) 43, 369-378

Original article

Walking and dairy cattle performance *

P D'Hour [1], A Hauwuy [2], JB Coulon [1], JP Garel [3]

[1] *INRA, Laboratoire d'Adaptation des Herbivores aux Milieux, 63122 Saint-Genès-Champanelle;*
[2] *SUACI Montagne, 73000 Chambéry;*
[3] *INRA, Domaine de la Borie, 15190 Marcenat, France*

(Received 26 March 1993; accepted 28 December 1993)

Summary — Differences in walking speed and milk yield were compared in dairy heifers and cows of 3 different breeds (Holstein, Montbéliarde, and Tarentaise) during 3 walking trials. Tarentaise cows walked faster than those of both other breeds. For walked distances of 5.6 and 3.2 km (trials 1 and 2, respectively) the mean walking speed of Tarentaises (1.71 and 1.43 m/s) was higher than for Montbéliardes (1.49 and 1.10 m/s) and Holstein (1.50 and 1.23 m/s). In trial 2, the Holstein and the Montbéliarde breeds both required more encouragement to move forward ($P < 0.05$) than the Tarentaise breed. In trial 3, milk production, milk composition and blood metabolites were evaluated following walked distances of 0, 6.4, 9.6 and 12.8 km. Milk yield and protein decreased ($P < 0.01$) in proportion to the distance traveled by 1.9 kg/d and –51 g/d, respectively, after 12.8 km. In contrast, milk fat, milk protein and blood-free fatty acids increased ($P < 0.01$) by 4.6 g/kg, 1.8 g/kg and 0.4 mmol/l, respectively, up to 12.8 km. Decreases in milk yield and protein were greater ($P < 0.01$) in Holstein cows than in the other 2 breeds. However, all cows regained their former level of milk yield within 3 d following the exercise. Five hours after walking, variation of glycemia was slight ($P = 0.06$) and the lactate level in the blood did not vary among walked distances. Only walked distances above 6.4 km brought about modifications in milk yield, milk composition and in blood-free fatty acids. These modifications were greater in Holstein cows than in the other 2 breeds.

dairy cattle / breed / walking / milk production

Résumé — Vitesse de déplacement et effet de la marche sur la production de vaches laitières de 3 races. *La vitesse de déplacement et les conséquences du déplacement sur les performances de génisses et vaches de race Holstein, Montbéliarde et Tarentaise ont été mesurées au cours de 3 essais. Sur un parcours de 5,6 km (essai 1), les génisses Tarentaises se sont déplacées plus rapidement (*P *< 0,01) que celles de race Montbéliarde ou Holstein (1,71 m/s* vs *1,50 m/s). Les résultats du second essai, réalisé avec des vaches primipares en lactation sur un parcours de 3,2 km, ont confirmé ceux du premier essai : la vitesse de déplacement des Tarentaises (1,43 m/s) est supérieure (*P *< 0,01) à celle des Holstein (1,23 m/s) et des Montbéliardes (1,10 m/s). Les vaches Tarentaises ont nécessité moins de sollicitations pour avancer (*P *< 0,05) et ont effectué moins de haltes que les animaux des 2 autres races. La production laitière n'a pas été affectée par ce déplacement. L'objectif du dernier essai était de comparer les conséquences de déplacements de 0 ; 6,4 ; 9,6 et 12,8 km sur la production laitière des vaches. La quantité et la composition du lait ont été mesurées au cours des 14 traites*

---

* This study was performed with the participation of the "Programme de Recherches-Développement des Alpes du Nord".

entourant le test. Les teneurs du sang en acides gras libres, en glucose et en acide lactique ont été mesurées 19 h avant l'exercice, immédiatement après et 5 h plus tard. Les quantités de lait et de protéines produites ont diminué pour les distances supérieures à 6,4 km (P < 0,01) atteignant –1,9 kg/j et –51 g/j pour 12,8 km. À l'opposé, la concentration du lait en matière grasse et en protéine a augmenté (P < 0,05) avec la distance (+ 4,6 et + 1,8 g/kg pour 12,8 km). La diminution de production laitière a été plus importante (P < 0,01) pour les vaches Holstein (–1,3 kg) que pour celles des 2 autres races (–0,6 kg). Les écarts de composition du lait ont été peu différents entre les 3 races. Dès le deuxième jour après la marche, les animaux ont retrouvé leur niveau de production initial. La teneur du sang en acides gras libres a augmenté fortement (P < 0,01) après la marche et ce pour les vaches ayant parcouru 9,6 et 12,8 km. La glycémie a légèrement augmenté (P = 0,06) 5 h après le déplacement. Le niveau d'acide lactique dans le sang n'a pas varié entre les traitements. Dans les heures qui ont suivi la marche, le comportement au pâturage des vaches (durée de pâturage, position couchée ou debout) n'a pas été modifié par le déplacement. Dans les conditions de cette étude, les animaux de race Tarentaise ont marché plus rapidement que les animaux des 2 autres races. Le dernier essai a également permis de préciser la diminution de production laitière due au déplacement et de mettre en évidence la plus grande sensibilité des vaches de race Holstein aux déplacements imposés.

vache laitière / race / déplacement / production laitière

INTRODUCTION

The distance pastured animals walk depends on many factors including size of the grazing area, the amount of grass available, the proximity of drinking water and management strategies (Anderson and Kothmann, 1977; Arnold and Dudzinski, 1978; Anderson and Urghart, 1986). The distance breeds walk vary, both in cattle (Arnold and Dudzinski, 1978; Lathrop *et al*, 1988) and in sheep (Squires *et al*, 1972) but are not consistent in cattle (Funston *et al*, 1991). When animals are required to forage over large areas, the breed's walking ability should be taken into account (Bibé and Vissac, 1979). Walking can be defined in terms of speed and described with a focus on the ease with which a herdsman can drive animals. Because walking is an activity that requires the expenditure of energy (Osuji, 1974) production may be influenced.

The increase in energy required during walking has been studied in cattle (Ribeiro *et al*, 1977; Pearson and Archibald, 1989; Lawrence and Stibbards, 1990). However, research on the effect of walking on milk production is minimal (Mathewman *et al*, 1989).

The objectives of this study were to determine differences in walking speed and ease of driving a group of cows from 3 different dairy cattle breeds over a fixed distance (trials 1 and 2) and if distance walked would influence milk yield and composition (trial 3).

MATERIALS AND METHODS

Animals

All trials were conducted in central France at an altitude of 1 100 m, between July and August in 1989, 1990 and 1991. Three breeds of dairy cattle were used. They were in good health with no feet or leg problems and had been reared together from 6 months of age on a experimental farm. The breeds were Holstein, Montbéliarde and Tarentaise (table I). Thirty-month-old non-lactating heifers were used in trial 1, 42-month-old lactating primiparous cows were used in trial 2 and 36- and 42-month-old lactating primiparous and multiparous cows, respectively, were used in trial 3. For trials 1 and 2, the animals were randomly assigned to 4 (trial 1) or 3 (trial 2) groups, each containing 5 animals of the same breed (table I). Animal groups were similar within breed, liveweight, stage of gestation (heifers), stage of lactation (cows) and milk production (cows). For trial 3, cows were randomly assigned within

Table I. Mean ages, liveweight, stage of gestation and stage of lactation for 3 dairy breeds (Holstein, Montbéliarde and Tarentaise) across 3 trials conducted between July and August in 1989, 1990 and 1991.

	Holstein	*Montbéliarde*	*Tarentaise*
Trial 1. Walking speed in heifers			
Age (months)	32 (± 1) *	32 (± 1)	32 (± 1)
Liveweight (kg)	577 (± 30)	555 (± 28)	491 (± 49)
Stage of gestation (d)	142 (± 26)	154 (± 35)	129 (± 49)
Trial 2. Walking speed and behaviour in primiparous cows			
Age (months)	43 (± 1)	43 (± 1)	43 (± 1)
Liveweight (kg)	559 (± 29)	552 (± 35)	499 (± 49)
Milk production (kg/d)	10.6 (± 3.0)	10.6 (± 1.1)	7.7 (± 2.0)
Stage of lactation (d)	203 (± 42)	229 (± 43)	193 (± 40)
Trial 3. Milk production and milk composition in walking cows			
Age (months)	50 (± 5)	50 (± 5)	51 (± 7)
Liveweight (kg)	539 (± 35)	537 (± 33)	482 (± 27)
Milk production (kg/d)	16.6 (± 3.4)	13.9 (± 2.0)	11.2 (± 1.9)
Stage of lactation (d)	198 (± 29)	210 (± 19)	186 (± 34)

* Standard deviation.

breeds to 4 groups. Each group contained 3 cows from each breed having similar liveweight, stage of lactation and milk production.

Groups of 5 animals of the same breed (trials 1 and 2) and groups of 9 animals of the 3 breeds together (3 cows of each breed, trial 3), were walked over a predetermined route of known distance. The animals were all familiar with the route having taken it at least once 8–10 d before the tests. This was their only training. For each trial they were accompanied by the same 2 people, one leading the way 10 m ahead of the group and the other following. The second walked at a constant speed of 0.8 m/s, remaining at least 1 m behind the last animal. If the last animal walked faster, the person at the back did likewise. If the animal slowed down to below 0.8 m/s or stopped, it was made to move ahead.

Feed

In all 3 trials, the animals had been on grassy mountain pasture for 2 months before the experiment began. *Agrostis tenuis, Poa pratensis* and *Dactylis glomerata* were the predominant grasses. The heifers (trial 1) grazed without supplementation under a rotational system consisting of 10–15 d in each of the 5 paddocks. The cows (trials 2 and 3) grazed on similar pastures under a rotational grazing system of 6 d per paddock; the total number of paddocks was 8. Four of the cows in trial 3 whose milk yield was higher than 17 kg/d (18.4–21.5 kg/d) were daily supplemented with 1.2 kg of feed concentrate (crude protein: 18.5%; crude fiber: 6.6% on a dry matter basis) during the experiment. Testing began 2 d after the animals had entered a paddock (trials 2 and 3).

Weather

Weather conditions in the immediate vicinity of the place of exercise were routinely recorded on the days the trials took place. No rain occurred on these days. The climatic conditions were those usually observed during this season. Hygrometry and windspeed varied little in the course of the trials (62%, 3 m/s) and the mean ambient temperature recorded under shelter, during the walking activity, ranged from 15 to 24°C.

Trial 1

Heifers in trial 1 were walked up and then down an ungraded 2.8 km route having an incline of 20 m/km. In the 4 tests carried out, the 3 breed groups (5 heifers) walked daily in a randomly predetermined order at 09.00, 10.30 and 14.00 h.

Trial 2

Each day in trial 2, 3 breed groups of 5 cows were walked once around a circular route which had a total elevation variation of 80 m, in a randomly predetermined order at 09.30 h (group 1), 11.00 h (group 2) and 13.30 h (group 3). The surface of the route varied. One third was tarred while the remainder was ungraded or grassy. After the morning milking at 06.30 h, the cows remained at pasture until the beginning of the exercise. Drinking water was provided *ad libitum*. After each walking test, they went back to pasture until the evening milking which began at 16.30 h. The experiment was repeated for 3 successive days.

Trial 3

The same route used in trial 2 was used in trial 3. After the morning milking (06.30 h) and before the beginning of the test, the cows remained in a dry lot with neither water nor food. The exercise began at about 09.00 h and finished around 11.30 h. First, a group of 9 cows consisting of 3 cows from each of the 3 different breeds were walked once around the 3.2 km route. They were joined by another group of 9 cows, for a second circuit, and then by a third group that was walked twice around the 3.2 km route. Hence, the first group walked 12.8 km (128 min), the second 9.6 km (98 min) and the last 6.4 km (66 min). A control group of 9 cows, comprising 3 cows of each breed, remained in a dry lot throughout the trial without access to food or water. At the end of the trial, the 4 groups returned to graze together in the same paddock. The trial was carried out on 4 different days, so all 36 cows were randomly tested in the 4 treatments with a minimum of 8 d (8–14 range) between walking trials.

Measurements

The total duration of exercise was recorded in each of the 3 trials. Animal behaviour while walking was recorded only during trial 2 and included the number of times animals shied, halted, required encouragement to walk or tried to flee. In trial 3 their activity at pasture was recorded every 10 min from the end of walking activity (12.00 h) to the evening milking (16.30 h) and included grazing, walking, standing and lying position.

Milk yields at the morning and evening milkings were weighed in trials 2 and 3 over a period of 7 d, including the test days. In addition, in trial 3, the chemical composition of milk (fat and protein contents) was measured by infrared spectrophotometry (Grappin and Jeunet, 1976) at each milking on the 2 d before exercise and 2 d afterwards.

Lactate (Noll, 1974), free fatty acids (FFA) (Chilliard *et al*, 1984) and blood glucose (Bergmeyer *et al*, 1974) levels were measured in trial 3. Individual blood samples were taken 19 h before exercise (16.30 h), immediately afterwards (11.30 h) and 5 h later (16.30 h). Each sampling series took 30 min. The concentrations of blood metabolites measured on the first day were discarded from the analysis because they included a large number of aberrant randomly distributed values (CV = 40% *vs* 20%).

Data processing

Trials 1 and 2

Data on walking speed of each group (trials 1 and 2) were analyzed by analysis of variance (GLM procedure: SAS, 1987) where the main effect was breed. Data on walking behaviour (trial 2) were processed according to a Kruskal–Wallis test (NPAR1WAY procedure; SAS, 1987).

Trial 3

Total daily milk yield and quality characteristics (fat and protein) were calculated by adding the evening milking data following the trial to that of the following morning. To assess the effect of walking on milk yield and milk composition we analysed the differences between data from the 2 d preceding walking and data from the day after. In addition, the effect of walking distance and breed was analysed for differences in production, milk composition, blood metabolites and behaviour at pasture, using GLM procedure (SAS, 1987). The factors introduced in the analysis were walking distance and breed. The interaction of breed and walking distance was consistently tested, but was never found to be significant ($P = 0.2$). The milk yield, milk composition and weight, measured before the experiment were introduced in the model as covariates, but were never significant ($P = 0.2$) and were thus discarded.

RESULTS

Trials 1 and 2

Cows covered 5.6 km (trial 1) and 3.2 km (trial 2) in mean time of 59 and 43 min, respectively. Tarentaise cows walked faster (+ 15 and + 25%, $P < 0.01$) than Holstein and Montbéliarde cows (table II). In 1989 (trial 1), the Holstein and Montbéliarde breeds had the same walking speed. The second year, the Holstein cows walked faster than the Montbéliardes (1.23 *vs* 1.10 m/s; $P < 0.01$). The differences in speed between groups of the same breed were not related to the mean weight of each group.

These differences in speed can be partially explained by the behaviour of the animals while walking (trial 2). The frequency with which the Montbéliarde cows, and to a lesser extent the Holstein, halted, shied, led or tried to flee was greater ($P < 0.05$) than in the Tarentaises (table II). Likewise, the Tarentaise cows required less encouragement from their accompaniers to walk than animals of the other 2 breeds, in contrast, they quickened the step spontaneously more frequently ($P < 0.05$; table II).

Performance and exercise (trials 2 and 3)

Milk yield was not affected ($P = 0.5$) in trial 2 by walking in any of the 3 breeds over a distance of 3.2 km. However, in trial 3 distances of 9.6 and 12.6 km decreased ($P < 0.01$) the daily milk yield of cows by 1.2 and 1.9 kg, respectively (table III, fig 1). The decrease was greater ($P < 0.01$) in Holstein cows compared to Montbéliarde and

Table II. Walking speed (m/s) and behaviour of 3 dairy cow breeds.

	Holstein	*Montbéliarde*	*Tarentaise*	*RSD* *
Mean speed (m/s)				
Trial 1 (5.6 km)	1.50 ^{a}	1.49 ^{a}	1.71 ^{b}	0.06
Trial 2 (3.2 km)	1.23 ^{a}	1.10 ^{b}	1.43 ^{c}	0.06
Behaviour during walking (trial 2)				
Number of:				
Halts	3.0	4.0	1.3	
Shies	2.0	3.3	2.0	
Flights	2.0 ^{A}	3.7 ^{A}	0 ^{B}	
Solicitations	17.7 ^{A}	17.7 ^{A}	9.7 ^{B}	
Speedings up	0.3 ^{A}	0 ^{A}	3.7 ^{B}	

* Residual standard deviation; values with different superscripts differ significantly (^{a,b,c} $P < 0.01$; ^{A,B} $P < 0.05$).

Table III. Effect of distance walked and dairy cow breed on differences in production between the day after exercise and the 2 previous days.

	Walked distance (km)				*Breed*			
	0	*6.4*	*9.6*	*12.8*	*Holstein*	*Montbéliarde*	*Tarentaise*	*RSD**
Milk production (kg/d)	-0.01^{a}	-0.47^{a}	-1.22^{b}	-1.93^{c}	-1.3^{a}	-0.62^{b}	-0.73^{b}	1.07
Fat content (g/kg)	0^{A}	2.6^{B}	3.85^{B}	3.97^{B}	2.53^{AB}	1.37^{A}	3.92^{B}	4.07
Protein content (g/kg)	0.09^{a}	0.41^{a}	1.05^{b}	1.38^{b}	0.51	0.77	0.91	1.15
Fat (g/d)	−2	17	−2	−28	−15	−8	11	61
Protein (g/d)	1^{a}	-5^{a}	-28^{b}	-51^{c}	-36^{a}	-13^{b}	-14^{b}	36

* Residual standard deviation; within distances and within breeds, values with different superscripts differ significantly (^{a,b,c} $P < 0.01$; ^{A,B} $P < 0.05$).

Tarentaise cows (1.3 *vs* 0.62 and 0.73 kg, respectively; table III).

The decrease in milk production was accompanied by an increase in milk fat ($P < 0.05$) and milk protein ($P < 0.01$; table III). The increase in fat content was lower ($P < 0.05$) in the Montbéliardes than in the other animals, but the overall amount of fat produced did not vary among groups. Breeds were similar ($P = 0.33$) in protein content but daily milk protein decreased ($P < 0.01$) with the distance of 12.8 km (51 g). The decrease was greater ($P < 0.01$) in Holsteins than the other 2 breeds. However, variations in milk yield and milk composition were transient, and began to level out on the 2nd day after walking and by day 6 there was no difference ($P = 0.8$) among groups (fig 1). The variations in performance within the same breed for animals, in the same walked distance were not related to liveweight or milk yield.

Blood metabolites

Immediately after exercise, blood FFA content increased ($P < 0.01$) from 0.12 to 0.4 mmol/l. The longer the distance, the more marked was the increase (table IV, fig 2). Five hours after exercise FFA levels were slightly higher ($P = 0.06$) in 9.6 and 12.6 km groups than in the control group. The levels of circulating blood glucose after walking did not vary among breeds and walked distances (fig 2). In contrast, 5 h after exer-

Table IV. Difference in blood-free fatty acid levels (mmol/l) between 19 h before walking and immediately after exercise (1) or 5 h after exercise (2).

	Differences in blood-free fatty acid levels (mmol)	
	(1)	*(2)*
Walked distance (km)		
0	0.12^{a}	0.01^{a}
6.4	0.25^{a}	0.05^{a}
9.6	0.47^{b}	0.14^{b}
12.8	0.40^{b}	0.20^{b}
Breed		
Holstein	0.35	0.12
Montbéliarde	0.28	0.09
Tarentaise	0.31	0.09
RSD *	0.21	0.12

* Residual standard deviation within distances and within breeds; values with different superscripts differ significantly (^{a,b,c} $P < 0.01$).

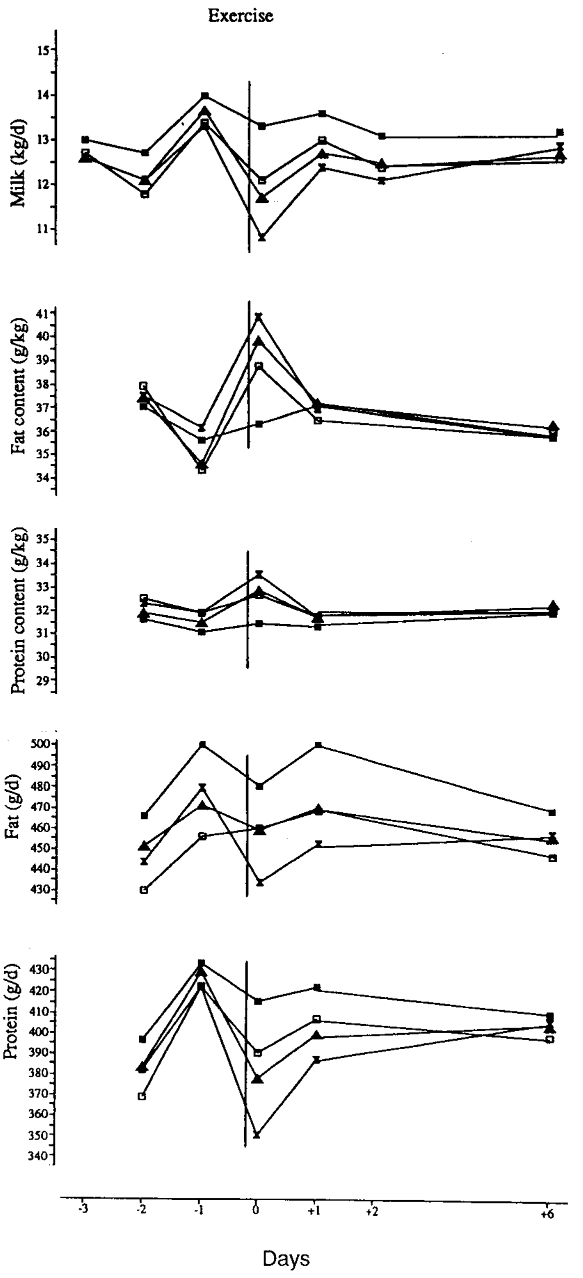

Fig 1. Mean daily milk production and milk composition in dairy cattle before and following walking. 0 (—■—), 6.4 (—□—), 9.6 (—▲—) and 12.8 (—⧗—) km.

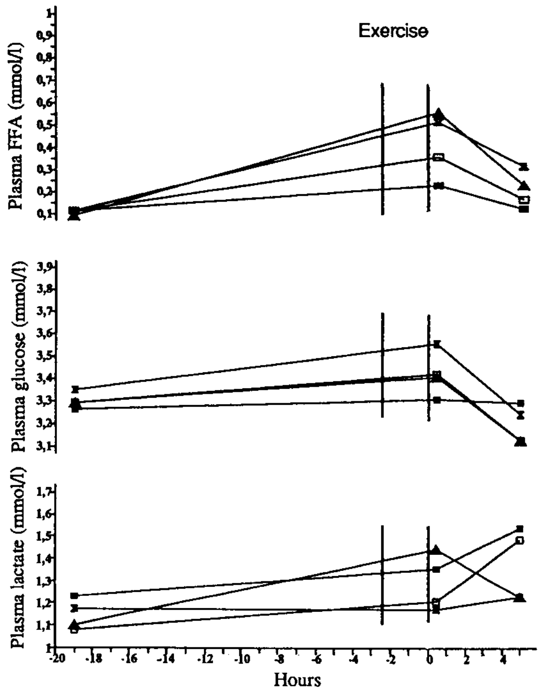

Fig 2. Changes in dairy cattle blood metabolites before and after walking. 0 (—■—), 6.4 (—□—), 9.6 (—▲—) and 12.8 (—⧗—) km.

cise, these levels were slightly lower (P = 0.06) than those recorded the day before in all the groups of animals that had been walking. Lactate content was not affected by walking and remained close to initial values (fig 2). There was no (P = 0.12) breed-related variation in blood metabolite content.

Activity at pasture (trial 3)

During the 270 min observation period, cows grazed for 132 min and remained lying and standing 51 and 87 min, respectively. There were no significant differences (P = 0.4) among cows having walked different distances or among breeds. The variations in the time spent grazing, by animals of the same breed during the same experiment, were not correlated (P = 0.42) with a decrease in milk production.

DISCUSSION

Walking speed

Walking speed differed among the cattle breeds studied, and in the ease with which they can be driven. The latter may be related to the docility of the animal, but in this experiment, could only be attributed to breed traits, since the animals of all 3 breeds were reared together from a young age. However Boivin *et al* (1992) did not observe any differences in docility between the 3 breeds of this study. The differences in walking speed we observed are consistent with the review of Arnold and Dudzinski (1978), who observed variations among breeds in distances covered at pasture. Other experiments (Anderson and Urghart, 1986; Funston *et al*, 1991) have shown that variations in distances covered at pasture are influenced by both intrinsic animal characteristics and management decisions.

Production and blood metabolites

Milk yield and milk composition were only reduced when distances greater than 6.4 km were walked. Our results follow those of Matthewman *et al* (1989), who found production temporally decreased but quickly recovered following walking distance of 8.8 km with an increase in elevation of 400 m. The rapid return to normal in our experiments may have been due to the fact that the animals were already used to exercise at 1 100 m (Matthewman *et al*, 1989). According to Arnold and Dudzinski (1978), cows at pasture cover between 3 and 6 km daily. Milk and protein productions were more affected by exercise in the Holstein cows than in the 2 other breeds. This difference was not due to the size of the animals or their milk yield, as shown in the variance analysis. Perhaps these animals are generally more stress-sensitive. This decrease in production is similar to that observed by Journet and Chilliard (1985) when there was a drastic reduction in energy supply. Stobbs and Brett (1974) have reported that milk and protein quantity decreased but the amount of fat produced did not vary probably because of a greater mobilization of lipid reserves. Pearson and Archibald (1989) noted an increase in FFA levels in the blood of cattle pulling a 25 kg load at a speed of 0.9 m/s during 30 min trials. This increase persisted 15 min after work had stopped. Thereafter the levels gradually decreased. The large differences in FFA levels seen in our study might therefore be partly due to the time taken (20–30 min) to sample all the animals after exercise. However, our results indicate high FFA levels even 5 h after exercise, suggesting that energy was still deficit. Immediately after exercise, Pearson and Archibald (1989) reported that levels of circulating blood glucose were higher, as a result of the increase in glucose supply due to the demand in the muscles. The difference among groups observed 5 h after exercise was low and is not in agreement with the decreases of 20% recorded by Matthewman *et al* (1989). The lactate level was not increased after exercise. In cattle, the anaerobic threshold is reached in muscles only when the animal makes a sudden intense effort (Pearson and Archibald, 1989), which was never required in our trials.

Behaviour at pasture

There was no difference among groups in grazing time. Aimals that covered the longest distance might have been expected to graze longer to satisfy increased energy needs. However, grazing time is only 1 factor affecting herbage intake (Forbes, 1988), other behavioural parameters including bite size and bite rate were not measured in our study.

CONCLUSION

Differences exist among dairy cattle breeds in walking rate over a set distance. Those animals having the slowest walking rate required greater attention from the people driving the cattle. A short-term decrease in milk yield and protein was observed after the animals had walked distances of 9.6 and 12.8 km. Holstein cows had the largest decrease compared with the other 2 breeds. However, it was not possible to dissociate breed traits from production level. In further studies it would be interesting to assess the effect of body size, mass and production level, on the walking ability of these cattle breeds, and to determine their ability to sustain long and repeated effort, as they have to on Alpine pastures.

ACKNOWLEDGMENTS

We thank E Albaret and A Mante for sampling and measurements and R Lefaivre for biochemical analysis of the blood.

REFERENCES

Anderson DM, Kothmann MM (1977) Monitoring animal travel with digital pedometers. *J Range Manage* 30, 316-317

Anderson DM, Urghart NS (1986) Using digital pedometers to monitor travel of cows grazing arid rangeland. *Appl Anim Behav Sci* 16,11-23

Arnold GW, Dudzinski ML (1978) *Ethology of Free-Ranging Domestic Animals* (Elsevier ed). Amsterdam, The Netherlands

Bergmeyer HU, Bernt E, Scmith F, Stork H (1974) D-Glucose determination with hexokinase and glucose-6-phosphate-deshydrogenase. *In: Methods of Enzymatic Analysis* (HU Bergmeyer, ed) Vol 3, 1196. Academic Press, London

Bibé B, Vissac B (1979) Amélioration génétique et utilisation du territoire. *In: Utilisation par les ruminants des pâturages d'altitude et parcours méditerranéens* (INRA Publication, ed) Versailles, France

Boivin X, Le Neindre P, Chupin JM, Garel JP, Trillat G (1992) Influence of breed and early management on ease of handling and open field behaviour of cattle. *Appl Anim Behav Sci* 32, 313-323

Chilliard Y, Bauchart D, Barnouin J (1984) Determination of plasma non-esterified fatty acids in herbivores and man: a comparison of values obtained by manual or automatic chromatographic, titrimetric, colorimetric and enzymatic methods. *Reprod Nutr Dev* 24, 469-482

Forbes TDA (1988) Researching the plant animal interface: the investigation of ingestive behavior in grazing animals. *J Anim Sci* 66, 2369-2379

Funston RN, Kress DD, Havstad KM, Doornbos DE (1991) Grazing behavior of rangeland beef cows differing in biological types. *J Anim Sci* 69, 1435-1422

Grappin R, Jeunet R (1976) Essais de l'appareil Milko-Scan 300 utilisé pour le dosage en série de la matière grasse et des protéines du lait. *Lait* 56, 498-520

Journet M, Chilliard Y (1985) Influence de l'alimentation sur la composition du lait. 1. Taux butyreux : facteurs généraux. *Bull Techn CRZV Theix, INRA* 60, 13-23

Lathrop WJ, Kress DD, Havstad KM, Doornbos DE, Ayers EL (1988) Grazing behaviour of rangeland beef cows differing in milk production. *Appl Anim Behav Sci* 21, 315-327

Lawrence PR, Stibbards RJ (1990) The energy cost of walking, carrying and pulling loads on flat surfaces by brahman cattle and swamp buffalo. *Anim Prod* 50, 29-39

Mathewman RW, Merrit J, Smith AJ, Phillips P, Oldham JD (1989) Effects of exercise on lactational performance in cattle. *Proc Nutr Soc*, 92A

Noll F (1974) L+-Lactate determination with LDH, GPT and NAD. *In: Methods of Enzymatic Analysis* (HU Bergmeyer, ed), Academic Press, London, Vol 3, 1475

Osuji PO (1974) The physiology of eating and the energy expenditure of the ruminant at pasture. *J Range Manage* 27, 437-443

Pearson RA, Archibald RF (1989) Biochemical and haematological changes associated with short periods of work in draught oxen. *Anim Prod* 48, 375-384

Ribeiro JM, Brockway JM, Webster AJF (1977) A note on the energy cost of walking in cattle. *Anim Prod* 25, 107-110

SAS (1987) *SAS STAT User's Guide*, Release 6.03 Edition, Cary, NC, USA

Squires VR, Wilson AD, Daws GT (1972) Comparisons of the walking activity of some Australian sheep. *Proc Aust Soc Anim Prod* 9, 376-380

Stobbs TH, Brett DJ (1974) Milk yield and composition of milk and blood as indicators of energy intake by Jersey cows. *Aust J Agric Res* 25, 657-666