Work stress and innate resistance of working bulls on two planes of nutrition: lessons from the N'Dama cattle of West Africa

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Abstract

Some results are presented from a study of the effects of nutrition and work on the genetic resistance of N'Dama cattle to trypanosomosis. We also investigated the commensurate nutrient allowance need to support the average work required for routine farm activities in tsetse-infested semi-arid regions of West Africa. Improved nutrition enhanced genetic resistance, supported higher work output before and after infection and enabled working infected bulls to hold body condition and live weight. Further, non-working bulls infected with Trypanosoma congolense *developed a more immediate and intense IgG and IgM antibody response to 33k Dalton protein, compared with their working counterparts. We therefore recommend that although working and non-working animals differed in their response to the 33k Dalton protein and crude* Trypanosoma congolense *antigen, a work force of up to 7% live weight and dietary allowance of at least 10 g of digestible organic matter intake per kg live weight will support the effective expression of trypanotolerance of N'Dama cattle working under semi-arid conditions.*

Introduction

Animal disease, in particular trypanosomosis, and inadequate supply of feed resources are two serious constraints plaguing the development of livestock production systems in the humid and sub-humid regions of Africa. As a result of the abundance of tsetse in West and Central Africa, trypanosomosis and other arthropod-borne diseases directly or indirectly remain a health hazard to man and ruminant livestock. Tsetse prevalence has a grave implication on animal productivity with severe economic and ecological consequences. A slight anorexia is a typical feature of trypanosomosis in recognised trypanotolerant breeds and reduced feed intake is known to impair host immune response, which can be complicated with the stress of work.

The classical definition of trypanotolerance has been described as the ability to survive and remain productive in tsetse infested areas without the use of chemoprohylaxis/therapy, where other breeds succumb (Murray *et. al.,* 1982). Although trypanotolerant animals are said to retain their level of productivity during infection, recent findings at the International Trypanotolerance Centre (ITC) show that trypanosomosis can present severe impairment of productivity in the N'Dama. Milk yield, tractive power and live weight gain are affected by trypanosomosis. There is increasing scientific and agricultural interests in the genetic resistance of cattle breeds of West and Central Africa to trypanosomosis and consequently, there is a need to better understand the inter-relationships between the parasitism/patho-physiology, innate resistance and productivity in terms of meat, milk and power.

This study investigated the relationship of work, infection and nutrition in N'Dama bulls subjected to two planes of nutrition.

Table 1: Time schedule of activities before and during the trial in Gambia

Date	Activities
August 1996	Infection with Trypanosoma congolense ITC961
October 1996	Termination of first artificial infection
November 1996	Infection with Trypanosoma congolense ITC962
January 1997	Termination of second artificial infection episode
February 1997	Trial starts - Training of animal handlers (drivers) and bulls
March 1997	Feed intake and productivity (work) data collection
May 1997	Infection with Trypanosoma congolense ITC971
July 1997	Trial ends - Treatment of all infected animals and weigh out (end of work)

Materials and methods

Animals

Thirty N'Dama bulls used in the trial had been exposed to diverse natural (accidental) and two artificial *Trypanosoma* infections before the trial began (Table 1). However, at the commencement of the trial in February 1997, all animals were observed to be clinically, and parasitologically negative for trypanosomosis. Thereafter, they all received a therapeutic dose of Diminazine aceturate 7 mg/kg live weight (*Berenil,* Hoechst, Germany).

Experimental activities

Prior to work data collection, all animals were placed in individual concrete floored stalls (2 m x 1.5 m) to allow for proper control of feed intake. The animals were allowed a period of four weeks to adapt to their new management, housing and feeding system during the trial and the work regime and their handlers. Working bulls worked for five consecutive days (Monday-Friday) for 14 weeks.

Treatment groups
All 30 bulls were tested for their willingness to work including their adaptation to the yoke and implements. The bulls were ranked on basis of their willingness and adaptation to work. The lowest ranked 10 bulls constitute the non-working or resting bulls. After separating the resting from the working bulls, all animals were ranked and paired on a weight basis. Each pair was placed on a high or medium plane diets such that heavy and light animals were evenly distributed across dietary levels. For every working pair on a high or medium dietary plane of nutrition, there was one resting bull on a similar nutrition regime.

Temperature measurements
Rectal temperature was measured using a digital clinical thermometer twice on each work-day (Monday – Friday) before feeding and again after work.

Feedstuffs and feeding allowance
All animals were offered the experimental diet for four weeks to allow for adaptation to the feed and feeding procedure. All animals were offered naturally dried herbage consisting of gamba grass hay (*Andropogon gayanus*; 940 g/kg DM, 20 g/kg CP), hand-chopped to 6-10 cm *ad libitum* as the basal diet supplemented with groundnut hay (GNH - *Arachis hypogea*; 930 g/kg DM, 84 g/kg CP). In addition, a 1:1 concentrate mixture of groundnut cake and rice bran were offered at 12 and 8 g/kg live weight (LW) for the high and medium diet respectively. All bulls were offered the concentrate diet at 08.00 hr after temperature readings had been completed. All animals were allowed access to the concentrate feed for 90 minutes - a reasonable time for the consumption of the concentrate, allowing for anticipated inappetence following infection. After all the concentrate had been consumed, or at the expiration of 90 minutes (which ever came first), the bulls were yoked in their designated teams (pairs) and taken to the track, about 200 m from the stalls. One driver worked each team. The drivers were allocated to teams at random on each working day.

The groundnut hay was offered immediately after work (11.00 - 11.30). The orts were weighed out at 15.30 h and at 16.00 h, the *Andropogon* hay ration was offered. *Andropogon* refusal was removed at midnight to avoid influence of feed intake on the pre-work rectal temperature readings and to avoid night dew effect on the dry matter content of the refusals. Representative samples of feed offered and refused were taken daily, bulked on a weekly basis and sub-samples were taken for dry matter (DM) and ash. The difference between amount of feed offered and refused was assumed as the total quantity of feed ingested by the individual animal. Dry matter intake (DMI) data collected daily was averaged on a weekly basis over a 13-week period. All animals were fed and watered at the same time irrespective of whether they were working or resting. Water was offered once daily at 14.00 h when the animals were allowed to drink to their fill. A mineral lick was available *ad libitum*.

Artificial challenge
After six weeks of work, a third artificial clonal infection was administered on all the animals by injecting 5 x 10^4 *Trypanosoma congolense* (ITC971) via the intradermal route.

Drivers and training
All drivers used in the study were literate with considerable experience in draught animal handling. All drivers received an additional seven days' training on data collection and animal handling. The working animals continued to train for fitness during a four-week adaptation period prior to their work regime. Training of the animals for fitness was conducted on the work track. Work animals were allotted to work teams consisting of two bulls of similar weight and fitted with a neck yoke. The animals pulled an empty iron sledge (29 - 33 kg) round a 2 km track divided in to four 500-m segments, on five days a week, for three weeks during training. In this period the distance worked was gradually increased as the animals developed fitness.

Work regime

The 20 well-trained bulls were ranked on a weight basis. Animals were allotted to high and medium nutrition levels in a manner that conferred similarity in absolute live weight distribution between both groups. Work was effected by each pair pulling the metal sledges, now weighted, around the 2 km-track for five laps per day, five days a week for 14 weeks. Each driver encouraged their team to go at its own pace until fatigued or completion of five laps (10 km) which constituted a days work. Each driver carried a note pad, pencil and stopwatch. They recorded the time at which their team passed each 500 m post. The time taken to complete each circuit of 2 km, was also recorded by an independent stationary recorder.

The average draught force (ADF) required to pull each sledge was adjusted by loading it with weighted sacks at the start of the experiment to be equivalent to an ADF of 70 N/100kg LW for each pair of oxen. Thereafter, the load was not adjusted to reflect any changes in live weight or track condition.

The ADF measured daily from the team and the speed and distance travelled by each team daily enabled the estimation of daily work output of the draught animal teams according to the method developed by Lawrence and Pearson (1985). Estimates of energy used (as net energy, NE) in work were calculated according to Lawrence (1985) and Dijkman (1993).

Health management, welfare and ethics

To eliminate possible adverse effects from tick-borne diseases and helminthiasis, all the animals were sprayed monthly with 6% flumethrin (Bayticol, Bayer) and drenched quarterly with 10% Fenbendazole (Panacur, Hoechst). In addition, for ethical reasons and to prevent undue suffering of experimental animals, an infected animal would be treated and withdrawn from the trial if it reached a pre-determined lower threshold of a packed cell volume (PCV) of 18% or if the symptoms of trypanosomosis became clinically severe. Spot-On was also applied at four weekly intervals to prevent accidental transmission of the infection. All bulls were vaccinated against pasturellosis, pleuro-pneumonia and anthrax. At the end of the trial, all animals were weighed and treated with Diminazene aceturate (Berenil, Hoechst) at 7 mg/kg LW.

Immunological assays

Sample preparation

Serum samples collected during the experimental phase were stored at –70 ^{o} C. Thereafter, the sera were sorted on collection day basis (30 animals x 30 sampling days). Using the ELISA with a modified amplified step (Harlow and Lane, 1988), each serum sample was tested individually in duplicate for antibody response by determining concentrations of immunoglobulins (IgG and IgM) against a soluble *T congolense* antigen prepared by freeze-thaw disruption of trypanosomes isolated from rats by anson-exchange chromatography.

Statistical analysis

Data were analysed using general linear models (SAS, v6.12). Analysis assumed a level of statistical significance of $P<0.05$ or less. The data were analysed using the model:

$$Y_{ijklm} = \text{animal (work health)}_i + \text{week (health)}_j + \text{diet}_k + \text{work}_l + \text{health}_m + \text{diet*work}_{kl} + \text{diet*health}_{km} + \text{work*health}_{lm} + \text{diet*work*health}_{klm} + e_{ijklm}$$

In the model, Y was variation and e was the residual term.

Results

General parasitaemia

Work and diet did not affect the length of pre-patent period judged by the appearance of trypanosomes in the blood by modification of the microhaematocrit centrifugation technique dark ground (MHCT-DG). Parasitaemia in both classes rose sharply to a peak in the second week post-infection from when it declined steadily until six weeks post infection when it stabilised at about a MHCT-DG score of +1. There were no significant effects of work and diet on the parasitaemia trend tested by MHCT-DG Mann-Whitney U-tests (Fowler and Cohen, 1993).

Table 2: Least square mean PCV values (and standard errors, se) of working and resting N'Dama bulls post-infection with *Trypanosoma congolense* on two planes of nutrition.

	Diet		
Work regime	**High**	**Medium**	**se**
Resting	26.3	26.0	0.14
Working	28.6	27.1	0.10

Packed cell volume

The work and diet effects on the PCV trend are shown in Table 2. All animals demonstrated a decline in PCV (as an index of the degree of trypanosome-induced anaemia) shortly after infection. In the pre-infection phase, the PCV ranged between 28% and 35% in individual bulls. However, no dietary effects were observed in resting and working animals. There were significant effects of work as working bulls had a higher (P<0.001) PCV compared with that of their resting counterparts (Table 2).

Feed intake

Table 3 shows the pattern of DMI of bulls on the two planes of nutrition offered in working and resting bulls during the study. All bulls on the high plane of nutrition had a significantly higher (P<0.001) intake of all components of the ration. Furthermore, all working bulls had a higher (P<0.001) intake of all components of the ration. As intended, there was a significant (P<0.001) dietary effect in the study. DMI trends showed identical and significant effects of infection of the animals in both dietary groups with a significant (P<0.001) decline in DMI post infection. Digestible organic matter intake (DOMI) was influenced by the diet and work regime (Table 3). Least square means of DOMI observed in the trial was between 9.5 and 12.5 g/kg LW or 38 and 51 $g/kg^{0.75}$ LW for bulls on medium and high planes of nutrition respectively. Least square mean DOMI for working and resting bulls was 10.2 and 11.8 g/kg LW or 41 and 48 $g/kg^{0.75}$LW. With a significant effect of infection on DOMI, the magnitude of post-infection anorexia was similar in all animals irrespective of dietary level. Feed intake dropped to 93% and 75% of pre-infection values (at 3 and 6 weeks post-infection respectively) in animals of both dietary groups.

Table 3: Least square mean dry matter intake of feedstuffs (g/d) offered in the trial and live weight (kg) of N'Dama bulls before (1) and after (2) infection with *Trypanosoma congolense.*

		High		Medium		
Feed	**Work**	**1**	**2**	**1**	**2**	**se**
Concentrate[1]	Resting	940	917	452	454	6.70
	Working	1454	1395	932	903	4.74
GNH	Resting	2940	2644	2161	2014	17.6
	Working	2970	2755	2935	2686	12.5
Andropogon	Resting	2436	2032	2344	2011	16.1
	Working	2445	2131	2333	2069	11.4
DOMI $g/kg^{0.75}$	Resting	52.1	45.2	36.9	31.1	0.24
	Working	55.6	50.9	45.6	39.5	0.17
Live weight	Resting	268	279	259	263	0.57
	Working	274	277	259	259	0.41

[1]1:1 Groundnut cake and Rice Bran

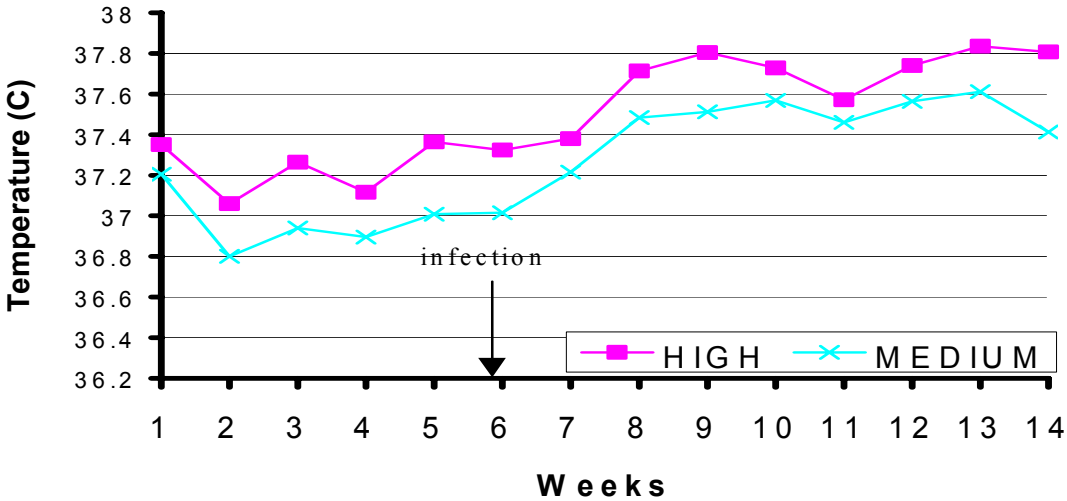

Figure 1: The effect of dietary allowance on pre-work rectal temperature of N'Dama bulls before and after trypanosomosis infection

Rectal temperature

The effects of pre-work mean rectal temperature (RT) are presented in Figure 1. Dietary regime and trypanosome infection significantly influenced the RT. Within two weeks of infection, the slight difference between rectal temperature (RT) in the pre-infection and the infection phase had attained statistical significance. Mean RT pre and post-infection were 37.0 °C and 37.5 °C respectively for working bulls and 37.1 °C and 37.6 °C respectively for resting bulls. Bulls on the high plane of nutrition had a persistently higher ($P<0.01$) rectal temperature compared with bulls on medium plane of nutrition. There was a slight increase in RT irrespective of dietary levels due to infection. Work regime did not have a significant effect on pre-work measurements of RT.

Live weight

Live weight pattern observed in the study was significantly influenced by dietary, infection and work factors (Table 4). Bulls on the high plane of nutrition were heavier compared with those on the medium plane with least square mean values of 274 and 260 kg (se 0.10) respectively. Moreover, there was a decline in live weight in the post-infection phase. Mean live weights were 265 and 269 kg (se 0.25) at the pre and post-infection phases respectively. Working animals lost more ($P<0.001$) weight compared with non-working animals irrespective of dietary level. With respect to DOMI, the dietary level did not only enhance live weight changes, but also significantly influenced infection and work (Table 4). The interaction between work and infection on live weight pattern was significant. Least square mean weight of working and resting animals was 267.

Immune response

Immune response to *Trypanosoma congolense* infection was monitored through the assay of the circulating immunoglobulins G and M post-infection. Graphical representation of the IgG is shown in Figure 2. OD values for IgG against *T. congolense* antigen rose gradually from day 10 post-infection and stabilised at about day 25 post-infection. Working and resting bulls mounted immediate IgM response, rising to a peak within 12 days after infection and stabilising at 1.5 and 2.0 levels for resting and working bulls, respectively. Similarly, IgG rose sharply attaining a peak concentration of 2.5 and 2.0 in resting and working bulls respectively. Both dietary and work regime had significant ($P<0.001$) effects on the pattern and magnitude of serum antibody response of the bulls to the antigen. The antibody response in both classes (IgG and IgM) followed a similar pattern. Working bulls on a high plane of nutrition demonstrated a higher ($P<0.001$) magnitude of post-infection IgG and IgM concentration compared with their resting counterparts on a high level of nutrition (Tables 5 and 6). The reverse however, was the case with the bulls on medium plane of nutrition where working bulls had a lower ($P<0.001$) concentration of antibodies compared to there resting counterparts. IgM patterns in working and resting bulls are presented in Figure 3.

Table 4: The effect of work and nutrition regimes on the live weight (kg) of N'Dama bulls before and after infection with *Trypanosoma congolense*

Diet	Work	Period		se
		Pre-infection	Post-infection	
High	Resting	268	279	0.57
	Working	274	277	0.41
Medium	Resting	259	263	0.57
	Working	259	259	0.41
Sub class means				
Diet	High	271	280	0.35
	Medium	259	261	0.35
Work	Resting	263	271	0.41
	Working	267	268	0.29

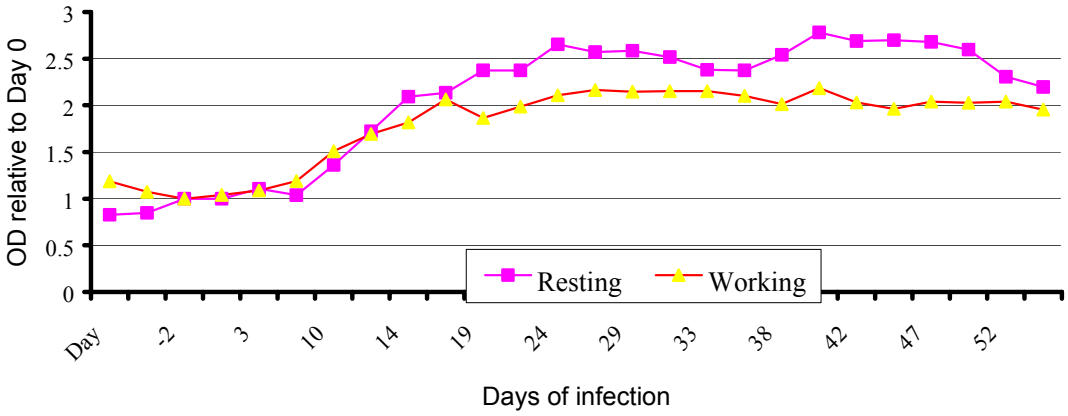

Figure 2: IgG response by working and resting bulls to *Trypanosoma congolense* infection in N'Dama bulls.

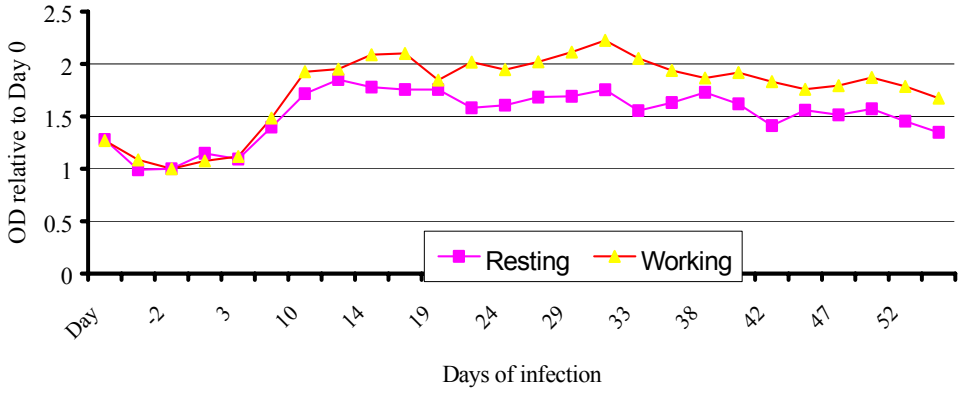

Figure 3: IgM response by working and resting bulls to Trypanosoma congolense infection in N'Dama bulls

Table 5: The effect of nutrition regime on the immune response (IgG, Optical density OD) values relative to day 0) of working and resting N'Dama bulls.

Work	Period	Diet		se
		High	Medium	
Resting	Pre-infection	0.89	0.89	0.16
	Post-infection	1.69	2.72	0.06
Working	Pre-infection	1.12	1.05	0.11
	Post-infection	1.99	1.78	0.04
Sub class means				
Period	Pre-infection	1.00	0.97	0.10
	Post-infection	1.84	2.25	0.04
Work	Resting	1.29	1.81	0.09
	Working	1.55	1.41	0.06

able 6: The effect of nutrition regime on the immune response (IgM OD values relative to day 0) of working and resting N'Dama bulls.

Work	Period	Diet		Se
		High	Medium	
Resting	Pre-infection	1.04	1.13	0.09
	Post-infection	1.35	1.80	0.03
Working	Pre-infection	1.22	1.02	0.06
	Post-infection	2.14	1.55	0.02
Sub class means				
Period	Pre-infection	1.13	1.08	0.10
	Post-infection	1.74	1.68	0.04
Work	Resting	1.20	1.46	0.04
	Working	1.68	1.29	0.03

Work output

Work was conducted during the late dry season (March – July 1997). All animals completed the set task allocated to each team on a daily basis. There was no cause to withdraw any animal or team due to stress of overwork syndrome, injury, fatigue or any apparent inability to work. The time taken to complete the 10 km a day (5 laps) ranged between 95 min to 205 minutes. The effect of the day of work did not attain significance, but there was a significant team effect, which was due principally to the inherent differences in the team's propensity to work. ADF required to pull the sledges was set at 70 N/100 kg LW at the commencement of the work and it remained relatively unchanged throughout the trial, as there was no appreciable change in the consistency of the track surface. Diet significantly influenced work time, speed of work, power output and NE_{work}. Bulls on the high dietary plane had a higher ($P<0.001$) speed of work and power output compared with those on the medium dietary plane irrespective of infection with trypanosomosis (Table 7).

In general there was a positive effect of diet on the speed of work and power output (Table 7). Mean power output rose sharply from the start of the trial to a plateau at the fourth week of the experiment. Bulls on the high dietary plane had a mean working speed of 1.46 m/s compared with 1.38 m/s of those on medium plane of nutrition. Consequently, power output was higher from bulls on the high dietary plane (517 W) compared with bulls on the medium plane of nutrition (486 W). Across the periods, mean speed of work pre-infection did not change significantly at the post-infection phase. However, infection had a negative effect on power output as mean power output declined ($P<0.001$) from 514 W to 490 W post-infection. As time of working and speed did not change appreciably post infection at least in the high plane of nutrition animals, then the decline in power output with infection must have been due to small decreases in the ADF, combined with small changes in time taken and speed (medium plane group). Clearly work performance was not dramatically affected by infection in any of the cattle.

Discussion

General

To improve understanding of the effects of nutrition and work on the genetic resistance of N'Dama cattle to trypanosomosis, the effects of work and level of feed intake on the immune response to artificial challenge with *Trypanosoma congolense* were investigated.

Table 7: Effect of nutrition on the estimates of power output in N'Dama bulls before and after infection with *Trypanosoma congolense*

	Pre-infection			Post-infection		
	High	Medium	Se	High	Medium	Se
Time (min)	115	121	0.78	114	124	0.47
Speed (m/s)	1.45	1.39	0.008	1.46	1.37	0.005
Power (W)	528	500	3.5	507	473	2.1
NE_{work} (MJ)	22.0	20.9	0.11	21.4	20.0	0.07
$Ne_{work}/NE_{maintenance}$	1.02	0.99	0.005	0.99	0.96	0.003
Weight (kg)	274	264	0.73	275	260	0.44

The patho-physiological response of the experimental animals to infection conformed to typical pathology of clinical trypanosomosis in trypanotolerant livestock (Murray *et. al*., 1983; Dwinger *et. al*., 1992).

Infection was established in all animals 8-10 days post-infection by the appearance of trypanosomes in the buffy coat. Consistent with previous findings, all bulls indicated a decline ($P<0.001$) in PCV and demonstrated low-grade anorexia following infection. Relative to pre-infection PCV values, there was only a decline of 20% without the need for chemotherapeutic intervention during the course of the trial. Anaemia or anaemic tendencies are typical events in trypanosomosis and up to 40% of pre-infection PCV have been lost to trypanosomosis induced anaemia in the N'Dama (Akinbamijo *et. al.,* 1997; 1998). Furthermore, neither work nor dietary levels had any significant effects when parasitaemia of working bulls was compared to those of the resting bulls. This observation is similar to the findings of Payne *et al*. (1991) in which work done by *Trypanosoma evansi* infected buffaloes did not stress the animals sufficiently enough to exacerbate the pathogenic effects of the infection.

The magnitude of anorexia was similar in all animals irrespective of dietary level. Feed intake dropped to 93% and 75% of pre-infection values (at 3 and 6 weeks post-infection respectively) in animals of both dietary groups. Post-infection, the bulls presented typical parasitological and serological evidences of clinical trypanosomosis with pronounced effects on live weight, power output, dry matter intake and the immune response. The speed of work, power output and live weight patterns indicated that in the post infection phase the added metabolic cost of infection exacerbated the condition of working bulls. Work routine remained constant and, despite the fact that working animals generally become fitter as the period of work progresses, the power output declined ($P<0.05$) in the acute phase of the infection as earlier indicated. This suggested that the presence of parasites in the blood or the ensuing acute phase syndrome had a direct effect on the bulls' ability to work. Clemence (1997) and Starkey (1982) had reported similar effects of work on disease resistance. A loss of up to 33% of draught power has also been reported in draught animals due to infection (Pearson, 1989a). Live weight was significantly affected by DMI, work and infection. Although feed intake was reduced by the same degree in both dietary groups, further analysis suggests that the role of the intermediary metabolism is currently underestimated in the trypanotolerance of N'Dama cattle. Complementary evidences from power output, live weight changes and haematology indicate that at the work regime and levels of nutrition used in the trial, the innate resistance mechanisms against trypanosomosis remained intact.

At first sight, evidences of clinical trypanosomosis observed would suggest a situation where nutrition and work regime do not pose a major threat to the hosts' ability to mitigate infection, but there was enough net energy available for weight gain especially in resting bulls pre- and post-infection. The data further showed that pre-infection, animals on high and medium nutrition gained 0.44 kg/d and 0.25 kg/d respectively. Post-infection, live weight gain dropped to 0.013 kg/d and -0.157 kg/d for high and medium bulls respectively. Post-infection weight loss in trypanotolerant animals is not unusual. Exceptional cases are where the nutrient level is high enough to mitigate endogenous catabolism (Akinbamijo, unpublished) and by bulls on the high dietary plane of nutrition. The magnitude of these changes is dependent on the severity and duration of infection. Given the dietary allowance (especially the high level), resting bulls did not indicate an enhanced control of parasitaemia. As the foregoing is one of the key indicators of the trypanotolerance trait (Dwinger *et. al*., 1992 Murray *et. al*., 1982), it suggests therefore, that neither the medium plane diet nor the workload was strong enough to induce the physiological stress that would compromise the host immune response. This is further corroborated by the live weight and PCV data, where animals on the medium plane diet had very slight weight loss and minimal anaemia compared to previous experiences with N'Dama at ITC (Akinbamijo *et. al.,* 1997; 1998). In addition, observations of signs of physical exhaustion during work such as severe fatigue, excessive drooling, noisy breathing and frequent rest stops were minimal. Consequently, none of the bulls was retired from work on the grounds of severity of infection or severe fatigue syndrome.

The ration of gamba grass (*Andropogon spp.*) was available *ad libitum,* however, because of its poor quality, the ingestion was restricted and hence could not augment the difference in nutrient intake between the medium and high diets (0.64 and 0.84 ME MJ/kg $LW^{0.75}$) or 41 and 54 g DOMI/kg $LW^{0.75}$ respectively. The speed at which the set work regime was completed was affected by nutritional status. There were considerable differences in the power output of animals offered high and medium level diets.

Animals on the high plane of nutrition were naturally heavier than their counterparts on the medium plane diet. Thus, as argued by Fall *et. al.* (1997), the contribution of the weight and speed to power output needs to be carefully interpreted. The two components of work output (force and distance) were standardised in this trial (7% ADF and 10,000 m).

As working animals may not increase intake immediately in response to increased nutrient demands for work on roughage diets (Pearson, 1989b), the fact that the bulls did not lose weight did imply that there was no cause for endogenous catabolism to meet energy requirements for work. Therefore, *ab initio* working animals were provided with an additional nutrient allowance to cover NE_{work} irrespective of the levels of nutrition. Consistent with the arguments of Fall *et. al.* (1997) and Bartholomew *et. al*. (1994), the effect of body size was one singular factor mediating power output. Consequently, we can infer that nutritional status is inherently beneficial to work output. Worthy of note however is that although the bulls on a medium plane diet commenced a negative weight balance shortly after infection, possibly due to a slight anorexia, the power output did not necessarily decline.

At the post-infection phase, intake had declined to 75% of pre-infection values with only a slight decline in power output. A negative energy retention would be in place as soon as $NE_{(maintenance+work)}$ exceeds exogenous supply of NE. Oxen and buffaloes reportedly lost weight during work in Nepal and Latin America (Pearson and Lawrence, 1992). The minimal weight loss post-infection observed in bulls on the medium plane of nutrition therefore strengthens the notion that the ability to hold body condition and to resist trypanosomosis is not compromised by work or nutrition. In addition, the N'Dama is known to be able to alter metabolic pattern during infection in a manner that optimises utilisation at the post-absorptive phase (Akinbamijo *et. al*., 1997). The degree of anorexia, weight loss, anaemia and general performance of the bulls post-infection confirmed the activation of a viable trypanotolerance.

Evidence from rectal temperature data suggests a feed effect, in which bulls on the high diet had a higher rectal temperature. Although the difference is statistically significant, severe physiological consequences are however doubtful. The increased rectal temperature is thus attributable to the physiological work of digestion and nutrient metabolism. The RT trend observed in the trial is especially consistent with the DOMI patterns.

Serological and immunological assays have shown that the taurine cattle – N'Dama (*Bos taurus*) consistently exhibit a superior resistance to trypanosomosis when compared with the humped Zebu breeds (*Bos indicus*) (Paling *et al.,* 1991). Working and resting N'Dama bulls were able to demonstrate consistent immunogenicity against a crude *Trypanosoma congolense* antigen within two weeks post-infection (Clemence, 1997). Results obtained by ELISA and confirmed by western immunoblotting antibody response (IgG and IgM) from this study also reinforced the observation that the immuno-competence of the animals was not compromised by either work or dietary allowance of more than 9 gDOMI/kg LW. Given the set levels of work and nutrition, working and resting N'Dama bulls were able to demonstrate antibody response (IgG and IgM) against trypanosomes. Both antibodies were elicited at peak serum concentrations within three weeks post-infection.

Although there was no difference in the length of pre-patent period, and contrary to the reports of Authié *et. al.* (1993, 1994) antibody (IgM) response was stronger in resting bulls attaining multiples of 3.5 and 1.5 of pre-infection values for resting and working bulls respectively. After the first pronounced peak, IgM OD declined progressively with minor irregular peaks in between. IgG response was different from the picture presented by IgM. A statistically significant effect of work was observed in the magnitude of response against the 33 k-Dalton antigen, examined by western blotting of soluble T-congolense extract against sera from infected animals (Akinbamijo *et. al.,* 1999). Pathological implications with respect to live weight, PCV and parasitaemia were minimal. As resting bulls attained peak concentration much earlier ($P<0.001$) than the working bulls (24 vs. 35 days most infection respectively) there was no reason to suggest significant differences in the ability to mitigate the infection.

Results from ELISA-based antibody response (IgG and IgM) indicate that the immuno-competence of the animals was not compromised by either work or dietary levels imposed. Levels of feed intake corresponding to availability of metabolic fuel had a positive effect on work output, a shorter time lag for immune response and reduced infection effect judged by live weight changes. Bulls on the high nutritional plane also had the higher ($P<0.001$) live weight gain.

Conclusions

The results obtained have confirmed a significant effect of nutrition on the general physiology and work performance and effective immune response against *Trypanosoma congolense* as enumerated below.

- Trypanotolerance goes beyond the ability to maintain immunogenic levels of relevant antibodies against trypanosomal antigens.
- A vital component of the resistance mechanism to infection is mediated via the ability to adjust and adopt frugal host metabolic processes such as

- Similar degree of anorexia in all animals irrespective of nutritional level.
- The ability of the N'Dama to suppress post-infection pyrexia (<1^{o}C) needs to be further investigated in relation to trypanotolerance. Prompt immune response to a 33 k-Dalton protein component of *T. congolense* is an important factor in trypanotolerance of N'Dama cattle.

- Resting animals developed a more immediate and intense IgG and IgM antibody response to 33 k-Dalton protein and crude *Trypanosoma congolense* antigen than did the working animals.
- However, an ADF force equivalent to 7% of live weight, sustained over 10 km, five days a week, and dietary allowance of at least 10 g of DOMI per kg live weight will support the effective expression of trypanotolerance of N'Dama cattle working under semi-arid conditions.

References

Akinbamijo, O. O., Bennison, J.J., Romney, D.L., Wassink, G.J., Jaitner, J., Clifford, D.J. and Dempfle, L. 1997. An evaluation of feed intake, digestive physiology and live weight changes of N'Dama and Gobra Zebu bulls during *Trypanosoma congolense* infection. *Animal Science* 65: 151-158.

Akinbamijo, O. O., Bennison, J.J., Jaitner, J., and Dempfle, L. 1998. Haematological changes in N'Dama and Gobra Zebu bulls during *Trypanosoma congolense* infection maintained under a controlled feeding regimen. *Acta Tropica* 69: 181-192.

Akinbamijo, O. O., Pearson, R.A. and Jones, T.W. 1999. Influence of work stress and nutritional status on tolerance of N'Dama cattle to a secondary trypanosomal challenge. Final ITC/CTVM Collaborative Technical Report prepared for DFID Holdback Project R6402H., DFID,London.

Authié, E., Duvallet, G., Robertson, C. and Williams, D.L. 1993. Antibody response to a 33 kDa cystein protease of *Trypanosoma congolense*: Relationship to 'trypanotolerance' in cattle. *Parasite Immunlogy,* 15: 465-474.

Authié, E. 1994. Trypanosomiasis and Trypano-tolerance in cattle: A Role for Congopain? *Parasitology Today* 10 (9) 360-364.

Bartholomew, P.W., Khibe, T. and Little, D.A. 1994. Effect of liveweight and body condition on work output from draft oxen. *Tropical Animal Health and Production*, 26:58-64.

Clemence, R.G. 1997. *Relationship between disease, work and nutrition*. PhD Thesis University of Edinburgh, Centre for Tropical Veterinary Medicine. 380pp.

Dijkman, J.T. 1993. *The measurement of draught ruminant energy expenditure in the field*. PhD Thesis. University of Edinburgh, Centre for Tropical Veterinary Medicine.

Dwinger, R.H., Clifford, D.J., Agyemang, K., Gettinby, G., Grieve, A.S., Kora, S amd Bojang, M.A. 1992. Comparative studies on N'Dama and Zebu cattle following repeated infections with *Trypanosoma congolense*. *Research in Veterinary Science*, 52: 292-298.

Fall, A., Pearson, R.A., Lawrence, P.R. and Fernadez-Rivera, S. 1997. *Feeding and working Strategies for Oxen used for Draft Purposes in West Africa.* ILRI, Nairobi, Kenya. 76pp.

Fowler, J. and Cohen, L. 1993. *Practical statistics for field biology.* John Wiley, England.

Harlow, E. and Lane, L. 1988. *Antibodies: A laboratory manual.* Cold Spring Harbour Laboratories, USA

Lawrence, P. R. 1985. A review of the nutrient requirements of draught oxen. In *Draught Animal Power for Production* (ed. J.W. Copland). Proceedings of an International Workshop in James Cook University, Townsville, Australia, 10-16 July 1985. ACIAR, Canberra, pp 59-68.

Lawrence, P.R. and Pearson, R.A. 1985. Factors affecting the measurement of draught force, work output and power of oxen. *Journal of Agricultural. Science (Cambridge)* 105: 705-714.

Murray, M., Morrison, W.I. and Whitelaw, D.D. 1982. Host Susceptibility to African Trypanosomes: Trypanotolerance. (Eds. J.R Baker and R Muller) *Advances in Para-sitology, 21: 1 – 68*. Academic Press London.

Murray, M., Trail, J.C.M., Turner, D.A. and Wissocq, Y. 1983. *Livestock Production and Trypanotolerance.* Network Training Manual. International Livestock Centre for Africa (ILCA) Addis Ababa, pp 5-9.

Paling, R.W., Moloo, S.K., Scott, J.R., McOdimba, F.A., Logan-Henfrey, L.L., Murray, M. and Williams, D.J.L. 1991. Susceptibility of N'Dama and Boran cattle to tsetse-transmitted primary and rechallenge infections with a homologous serodeme of *Trypanosoma congolense*. *Parasite Immunology* 13: 413-425.

Payne, R.C., Djauhari, D. Paroutomo, S., Jones, T.W. and Pearson, R.A. 1991. *Trypanosoma evansi* infection in worked and unworked buffaloes (*Bubalus bubalus*) in Indonesia. *Veterinary Parasitology* 40: 197-206.

Pearson, R.A. 1989a. Reduced work output of well-fed buffaloes (*Bubalus bubalis*) pulling carts on the Terai in East Nepal. *Tropical Animal Health and Production* 21: 274-276.

Pearson, R.A. 1989b. A comparison of draught cattle (*Bos indicus*) and buffaloes (*Bubalus bubalis*) carting loads in hot conditions. *Animal Production* 49: 355-363.

Pearson, R.A. and Lawrence, P.R. 1992. Intake, digestion, gastro-intestinal transit time and nitrogen balance in working oxen: Studies in Costa Rica and Nepal. *Animal Production* 55: 361-370.

Starkey, P.H. 1982. N'Dama cattle as draught animals in Sierra Leone. *World Animal Review.* 42: 19-34.