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A Highlight on the Effect of Heat Stress on the Dairy Cattle Performance

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Abstract: In hot climate, the heat stress means that the environmental effective temperature is higher than the animal's thermo neutral zone. The effective temperature is affected by air temperature, relative humidity, air movement and solar radiation. The degree of heat stress to which the cattle are exposed is estimated using the temperature humidity index (THI). The production and reproduction of the dairy cattle are adversely affected by the heat stress. The adverse effects are: the hypothalamic- hypophyseal-ovarian axis fails to exhibit the oestrus (particularly in the buffaloes), the cows reduce their feed intake, the concentrations of the metabolic hormones are decreased, and the acid- base status of these cows is altered. Subsequently, the fertility of the buffaloes and the milk production of the cows would be decreased. The various strategies could be used to improve the production and reproduction in the heat-stressed cattle. As feeding strategy, the cattle should be fed through the high density diets (high concentrate and low fibre or, supplemented with fat) having low level of crude protein or low degradability in the rumen. Also, the diets of the heat- stressed cows should be supplemented by the buffers in the positive formula of the dietary cation-anion difference (DCAD) expressed as (Na+ K- Cl) m Eq. g^{-1} dry matter. The DCAD has been suggested to improve the acid-base status. Moreover, the heat-stressed cattle should be shared with fans and sprayers as a management strategy. Actually, the feeding strategy must be paralleled with the management strategy for the heat-stressed cows.

Key words. heat stress, dairy cattle, milk production, reproduction

INTRODUCTION

In hot climate, heat dissipation through conduction, convection, evaporation, and radiation become less effective as temperature and humidity rise, causing an increase in body temperature. The degree of heat stress is estimated using temperature humidity index (THI). Estimates of THI are calculated using the following formula. THI=Td- [(0.55-(0.55RH) × (Td-58)], where. Td is dry –bulb temperature in Fahrenheit and RH is relative humidity expressed as a proportion (National et al., 1976). At the daily average of THI ≥ 72, the dairy cattle are considered under the heat stress. However, the negative effects of the heat stress on the high dairy cows begin at lower minimum and average daily THI values of 65 and 68, respectively (Johnson et al., 1963). It is of interest to report that due to the environmental differences between on-farm and meteorological station readings, the readings from meteorological stations should not be used as an indicator for estimating the degree of heat stress to which the cattle are exposed (Shock et al., 2016).

Concerning the factors affecting the susceptibility to the heat stress, the sensitivity is higher in the high yielding cows. Also, this sensitivity is affected by the colour and thickness of the animal skin, and by the sweat glands number per the unit area of the skin. In Egypt, the buffalo's distribution differs all over the country. The 63, 20, and 17% of the total number of the buffaloes are in the Lower, Middle, and Upper Egypt, with the average temperature in the summer ≤ 30, ≥35, and ≥ 40 ° C, respectively. In the Upper Egypt, the buffalo is mainly considered as a working animal not as a dairy animal (Cockrill et al., 1974). The cattle react against the heat stress by increasing each of the water intake, the evaporated water loss, and the respiration rate, but decreasing the feed intake. Generally, in heat-stressed cattle, the common adverse effects are reducing of the rate of weight gain, the fertility (both sexes) and the milk yield. These effects decrease the productivity of the herd, with consequences for economic viability(Bucklin et al., 1991; Robert J et al., 2014).

Several strategies have been suggested to minimize the adverse effects of the heat stress on the dairy cattle productivity. One strategy has been suggested to modify the environment around the animal by shading to reduce solar radiation or by using sprinkler to increase the evaporative cooling. The other strategy has been suggested to modify the diet ingredients to decrease the heat production. This article highlights the effects of the heat stress on the performance of the dairy cattle.

THE NEGATIVE EFFECTS OF THE HEAT STRESS ON THE DAIRY CATTLE PERFORMANCE

Effect of the heat stress on the fertility

In summer, the fertility of buffaloes is low due to the disruption in the profile of the secreted sexual hormones, causing inhibition of the ovaries activity called anoestrus. Summer anoestrus is affected by the environmental factors (scant hair coat, high relative humidity, thermal stress, and photoperiod), the hormonal factors (prolactin, melatonin, follicle stimulating hormone, thyroid hormones, ovarian hormones, corticosteroids), and the nutritional factors (summer lignified forages poor in protein, low feed intake). The heat stress is the most important one of these factors.

To illustrate the effect of the heat stress on the buffalo fertility, it is notable to simplify the review of Das and Khan (Das et al., 2010) which has been titled by summer anoestrus in buffaloes as shown in Fig. 1.

In this review, it has been reported that various strategies like environmental modification, nutritional management and hormonal therapy can be used to improve the reproductive efficiency in buffaloes. The environmental management is the best approach while the hormonal treatments can result in different degrees of the success. The writers have added that showering, splashing, sluicing or water spraying, loose housing system, and a shift from day to night grazing practices are advocated for improving the fertility in heat-stressed buffaloes.

In this respect, it is of interest to report that calves born to cows exposed to heat stress during late gestation have lower birth weight and weaning weight and compromised passive immune transfer compared with those born to dams that are cooled. Additionally, heat stress during the last 6 wk of gestation induces a phenotype that negatively affects survival and milk production up to and through the first lactation of offspring. It is notable to report that in the cooled cows, fans ran continuously, whereas sprinklers turned on automatically for 1.5 min at 6-min intervals when ambient temperature exceeded 23.9°C. After calving, cows from both treatments were housed in the same free stall barns, cooled by sprinklers and fans(Monteiro et al., 2016).

Effect of the heat stress on the dry matter intake and milk production

It is well known that dairy animal reduces its feed intake during the hot stress as a thermoregulation effort to prevent an excessive increase in body temperature via decreasing its heat production. By reducing the feed intake, the digestible energy, the metabolizable energy, and the net energy are decreased, so, the energy retention is decreased. Subsequently, the energy lost in the faeces, urine, and methane emission, or as a heat increment would be decreased. Thus, both the heat production and milk yield of the dairy animal would be decreased. Also, as an attempt of the animal to reduce its heat production, the concentrations of the plasma somatotropin and triiodothronine are declined under the heat stress. Moreover, the heat stress has a strong influence on the dry matter intake in the high yielding dairy cattle, whereas, dry matter intake (DMI) decreases by 2 percent for every 1°C rise in the daily temperature average above 25° C (Magduband et al, 1982; Johnson and et al, 1988; Mc and et al, 1996).

THE ENVIRONMENTAL STRATEGY DURING THE HEAT STRESS

In summer, less heat can be lost via the sensible routes (radiation, conduction, and convection) while more heat can be lost via the evaporating system (sweating and panting). So, the management of the dairy cattle would be a vital tool to eliminate the adverse effects of the heat stress on these cattle. Actually, Igono *et al.* (Igono et al., 1987) have observed that the milk yield could be increased and both rectal temperature and milk temperature could be decreased significantly in the heat stressed cows by using shade plus fan and spray compared with shade only.

It is well known that a lot of water is used in the sprinklers and water is considered as a scarce resource. So, Chen *et al.* (Chen et al., 2016) compared three sprinkler flow rate (0, 1.3 or 4.9 L min^{-1}(both 3 min on and 9 min off, 24 h d^{-1})) for high- producing lactating cows under warm weather (33± 3°C) having a shaded feed bunk. The authors have found that the flow rate 1.3 L min^{-1} had cooled cows more efficiently than 4.9 L min^{-1} despite using 73% less water. Also, they have noticed that DMI was not affected significantly by the water spray. However, the milk yield was significantly affected by sprinkler flow rate. Milk yield was 42.6, 46.3, and 45.9 kg d^{-1} for unsprayed the control cows, and those sprayed with sprinklers flow rate 1.3, and 4.9 L min^{-1}, respectively. The effects of cooling cows with water spray on the dry matter intake and milk production have been shown in Fig.2.

Moreover, the effect of cooling stressed cows during the last 3 wk. of gestation on the DMI and milk production was evaluated by(Karimi et al., 2015) Twenty dry cows were randomly divided into two equal groups, cooled and heat stressed cows. The average of THI during the last 3wk. of gestation was 69.7. Dry matter intake was recorded from 21 day pre calving to 21-day post calving, and milk yield was measured daily up to 180 days in milk. The results simplified in Table 1 confirm that the heat stress abatement in last 3 wk. of gestation improves the cows' performance in the subsequent lactation.

FEEDING STRATEGY DURING THE HEAT STRESS

Role of increasing the dietary energy density during heat stress

On the basis of reducing DMI by heat stress, the workers have tended to increase the dietary energy density by using diets containing high concentrate and low fibre or diets supplemented with fat for the heat-stressed cattle. Fat has a low heat increment, but its upper limit of the diet is 6 to 7% of the dry matter intake(Knappand et al., 1991; Wu etal., 1994; Drackley et al., 2003; West, 2003; Halachmi et al., 2004).

The addition of the long-chain fatty acids (LCFA) to the diets increases the metabolizable energy of the diet by decreasing the production of methane. Also, the LCFA transportation from the diet to the mammary gland is energetically more efficient than de novo synthesis of LCFA from acetate (de novo pathway is occurred by feeding cattle on high forages diet). So, less heat is dissipated per unit of net energy intake from dietary LCFA than from dietary forages. Consequently, supplemental LCFA has been suggested for cattle under heat stress (Palmquist et al., 1980; Chilliard et al., 1993).

Because, heat-stressed dairy cows are bio energetically similar to early-lactation cows, the dietary energy may be inadequate to support milk and milk component synthesis. So, Moore *et al.* (Moore et al., 2005) have fed heat-stressed cows on the diets supplemented with the conjugated linoleic acid (CLA). The author shave found that energy balance was improved by CLA supplementation compared with control (3.7 vs. 7.1 M cal d^{-1}, respectively) but had no effect on either dry matter intake or milk production.

It is worth to report that decreases in dry matter intake by an average 0.7 kg/day as a result of fat supplementation are common in 22 experimental treatments as it has been reviewed by (Chilliard, 1993). At least, two explanations have been suggested for this phenomenon. The first may be the decrease in the ruminal fibre digestion by adding fat and the second may be the sensitivity of some factors (may be hormones) to fat supplementation.

On the other hand, shredded beet pulp has been substituted for maize silage in diets fed to dairy cows under the ambient heat stress (Naderi et al., 2016). The authors have found that neither DMI nor nutrient digestibility was affected by treatments; however, the milk yield was significantly increased and the milk fat content was significantly decreased. The authors have attributed the increasing in the milk yield and the decreasing in the fat content to the increasing in the propionate concentration and the decreasing in the acetate concentration, respectively. Obviously, under heat stress, the increasing in the concentrate level improved the milk production via the changing the ruminal fermentation pattern not via the dry matter intake (DMI) controlling. The level of the substitution and its effect on milk yield and milk fat are shown in Table 2.

Finally, it could be reported that despite of increasing the energy density of the diet either by supplying of fat or by increasing starch-based concentrate resulted in similar increases in the milk production, the apparent efficiency of the milk production (kg of milk solids kg^{-1} of DMI) was greater for diets supplemented with fat than diets supplemented with starch.

Role of the dietary protein during the heat stress

With regard to the role of the dietary nitrogen (N) during heat stress, it could be reported that each 1 g of excess N above requirements is associated with an energy loss of 7.2 or 5.5 K $calg^{-1}$ of N as it was reported by Tyrell *et al.*, (Tyrell et al., 1970) and Higginbotham *et al.*, (Higginbotham et al., 1989) respectively. Moreover, almost all of the protein in excess of dairy cows' requirements (19 or 23 % CP diets) is excreted in the urine as urea. The energy cost associated with synthesizing and excreting urea is accounted for the reduced milk yield (Oldham, 1984). Furthermore, high dietary protein can increase the water needed for the urinary disposal of urea. This extra demand may contrast with the increased water requirements for the cooling of heat-stressed cows (Shalit et al., 1991; West, 1999). On the basis of the previous statements, the level and the ruminal degradability of the dietary protein would be the critical items under the heat stress.

It is of interest to report that the high protein diets (18.5%) of high rumen degradability decreased the milk yield in the shaded cows subjected to the hot stress compared with high protein diets of low degradability or low protein diets (16.1%) of high or medium degradability. Moreover, diets containing 15.3% crude protein of which 35% is considered as the un- degradable protein (5.4% of dry matter) may be adequate to maintain the milk production in heat- exposed cows kept under evaporative cooling. As a general, the ruminal degradable protein must not exceed 61% of the dietary crude protein (Higginbotham et al., 1989; Huber et al., 1940; Arieli et al., 2004).

Actually, feeding of low degradable protein improved the milk production during the heat stress, provided it should be from a good quality. In a trial, diets with the similar ruminal un-degradable protein (RUP) content from high quality (blood, fish, and soybean meals) or low quality (maize gluten meal) proteins were fed to the cows housed in shade or shade plus evaporative-cooled environments. And, it was found that the cows fed high quality RUP yielded 3.8 and 2.4 kg more milk in the evaporative-cooled and shaded environments, respectively, than those fed low quality proteins (Taylor et al., 1991; Chen et al., 1993).

Role of the dietary cation-anion difference during the heat stress

As a feeding strategy, heat-stressed cattle were fed low-forage or high-starch diets. So, these cattle may be more susceptible to metabolic acidosis. Also, the heat stress is often accompanied by a respiratory alkalosis and a slight metabolic acidosis which may be happened as a compensatory response. On the basis of these findings, the diets of these heat stressed cattle should be supplied with the buffers such as $NaHCO_3$ and K_2CO_3. Actually, higher dietary Na or dietary K increases the alkalinity of body fluids. But some workers have suggested that the dietary cation-anion difference may be a superior measure of these electrolytes effects than their effects as individual electrolytes (Schneider et al., 1988). The term dietary cation-anion difference (DCAD) refers to the difference, in equivalents, between strong cations and anions in the diet. One of the formulae used to calculate this DCAD has been suggested by Mongin (Mongin et al., 1980) as ((Na +K)– Cl) m Eq. $g^{-0.01}$ dry matter (DM).

DCAD is a method by which the acid-base chemistry of the cow can be altered by manipulating the amount of Na, K, Cl included in the diet. Positive DCAD (+DCAD) eliminates the physiologic acidosis by raising buffering capacity of the blood, reflected by increased blood pH and blood bicarbonate (HCO_3^-) concentration. Moreover, the meta-analysis reported by Iwaniuk and Erdman (Iwaniuk et al., 22015) has suggested that DCAD has a significant positive effect on the productive performance via changing the rumen environment and improving acid-base homeostasis in the dairy cows. It is notable to refer to the meta-analyses of multiple macro mineral studies reported by Hu and Murphy (Hu et al., 2004) who have found that the DMI was improved at a DCAD of + 40 m Eq.$g^{-0.91}$ DM and the milk yield was improved at + 34 m Eq. $g^{-0.01}$ DM intake by heat- stressed cattle.

In general, the optimum range for the DCAD was between +25 and +50 m Eq.$g^{-0.01}$ DM. And the milk production was not improved when the DCAD was elevated outside of this optimum range even with altered the ratio of K to Na in the diet (Sanchez et al., 1996; Sanchez et al., 1994).

On the other hand, it was found that the DCAD ranging from +17 to +38 increased the DMI, but the DCAD range from +25 to +40 m Eq.$g^{-0.01}$ DM maximized the milk yield of the heat-stressed cows (Sanchez etal., 1996) in another study, it was found that the DMI and the milk yield were improved quadratically and linearly, respectively, as the DCAD range increased from -12 to +31 m Eq.$g^{-0.01}$ DM (West et al., 1991). These two studies implied that the higher DCAD may be required to improve the milk yield not to improve the DMI in the heat-stressed cattle.

It is of interest to illustrate that the positive DCAD can also affect the efficiency of the dietary protein in the heat-stressed cows. This finding could be explained on the basis that the low blood urea nitrogen concentration in cows fed a high DCAD reflects the possibility of enhanced microbial ammonia utilization resulting in greater microbial crude protein. Moreover, increased the blood concentration of essential amino acids (AA) in heat stressed cows fed diet with +25 DCAD suggests that the positive DCAD reduced the need for AA degradation to maintain acid- base balance, sparing AA for other uses. Thus, not only DCAD alters acid-base chemistry, but it may also affect AA metabolism. The mechanism of this effect is unclear and needs further investigation (Wildman et al., 2007).

It is notable to illustrate the study of Shahzad *et al*., (Shahzad et al., 2007). who have investigated the effect of the DCAD ((Na+ K- Cl+ S)) on the buffalo performance during hot summer. Four diets were formulated to have their DCAD as follows. -110, +110, +220, and +330 m. Eq.kg^{-1} DM. Twenty early lactating buffaloes (*Nili*

Ravi) were randomly allocated to the four dietary treatments in a randomized block design. The experiment lasted for the five summer months (June to October). The authors have evaluated these treatments on the blood pH, blood HCO_3, DM intake, and milk yield. Also, they have monitored the services per conception and conception rate during the experimental period. The results of this study are shown in Fig.3. a, b, c, d, e and f, respectively. The authors have concluded that high DCAD improved the studied parameters.

Conclusion

It could be concluded that the production and the reproduction of the dairy cattle are adversely affected by the heat stress during the hot climate. These adverse effects could be eliminated by the feeding strategy and the management strategy. Both strategies must be paralleled. All cattle exposed to hot climate must be shaded, and cooled. Lactating cattle exposed to the heat stress should be fed high density diets having low level of crude protein, and the dietary cation- anion difference of these diets should be within the optimum range of + 25 to 50 m. Eq. $g^{-0.01}$ dry matter.

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Table1. Effect of cooling on some physiological and productivity parameters in lactating cows

Item	Heat-stressed cows	Cooling cows
Rectal temperature (°C)	39.5	39.2
Respiration rate (breath/min)	70.4	63.3
Dry matter intake (kg/day)	13.7	15.5
Milk during 180 day in milk (kg/day)	40.5	44.6

Table 2. Effect of increasing concentrate level (L) on the milk yield and fat in cows during heat stress

Item	L 1	L 2	L 3	L 4
Maize silage (g/100g dry matter)	16	8	12	0
Shredded beet pulp (g/100g dry matter)	0	8	4	16
Neutral detergent fibre (g/100g dry matter)	21.3	16.5	14.1	11.70
Non-fibre carbohydrates (g/100g dry matter)	39.2	40.9	43.2	43.4
Milk yield (kg /day /head)	38.5	39.3	40.9	39.0
Milk fat content (g/100g milk)	3.46	3.47	3.27	2.99

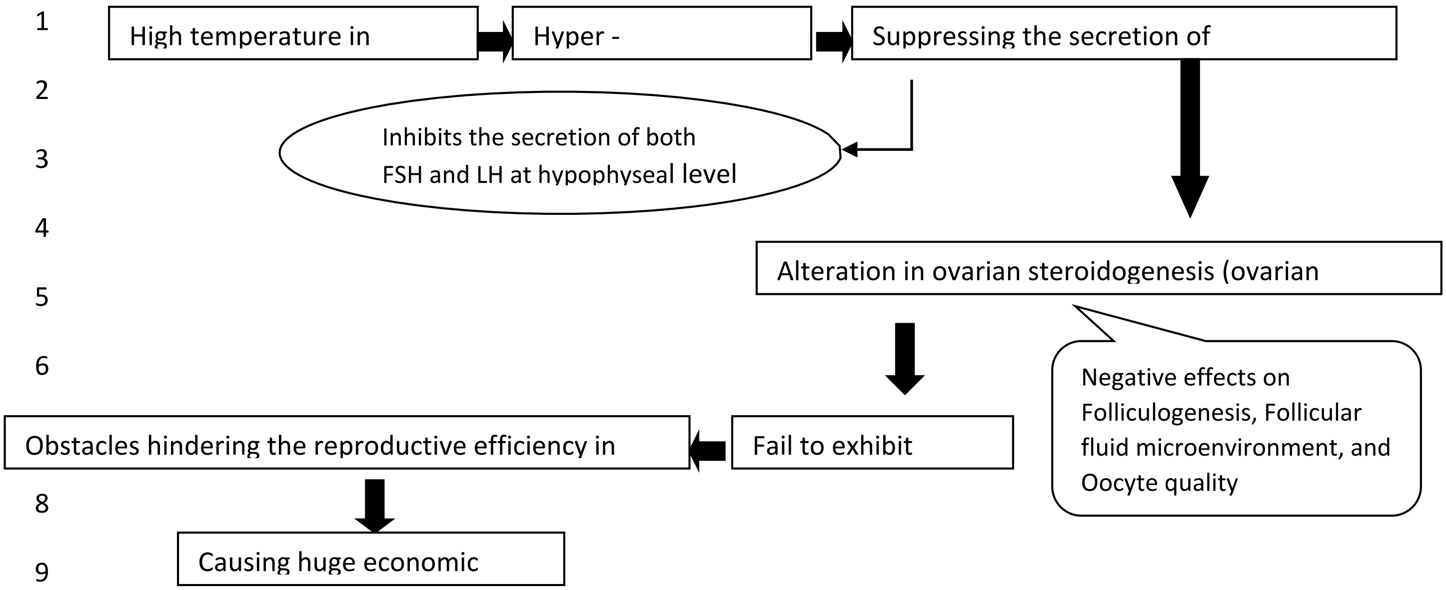


Fig. 1. Effect of the heat stress on the hypothalamic- hypophyseal- ovarian axis

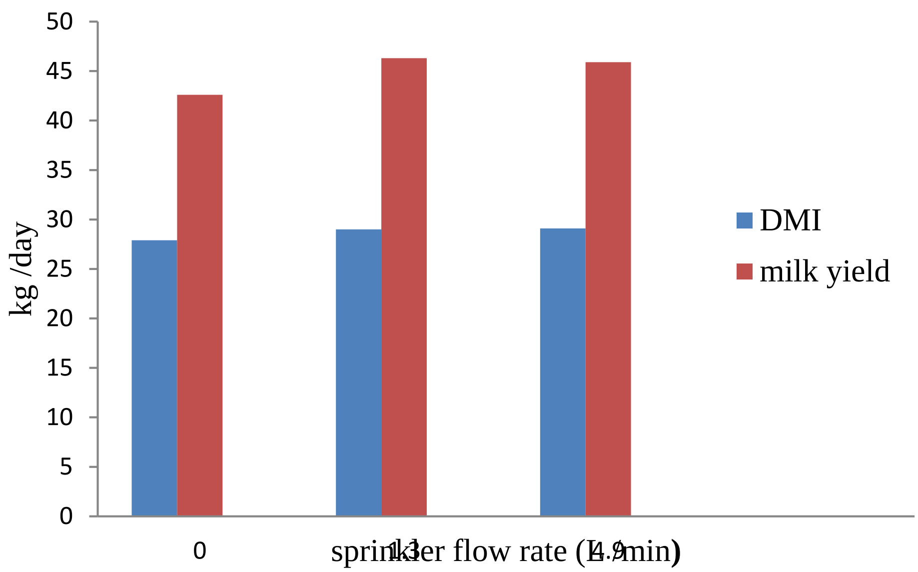
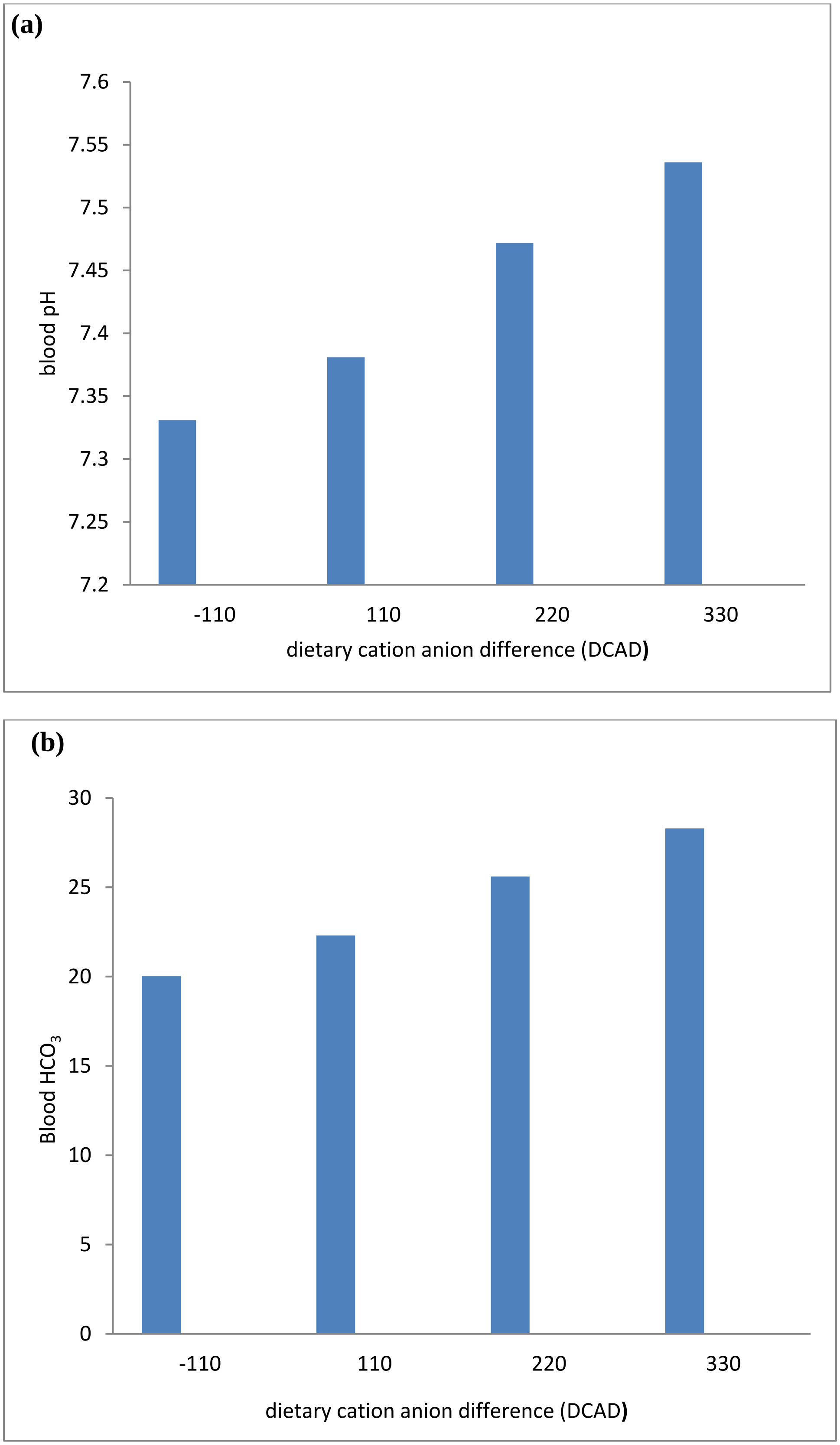
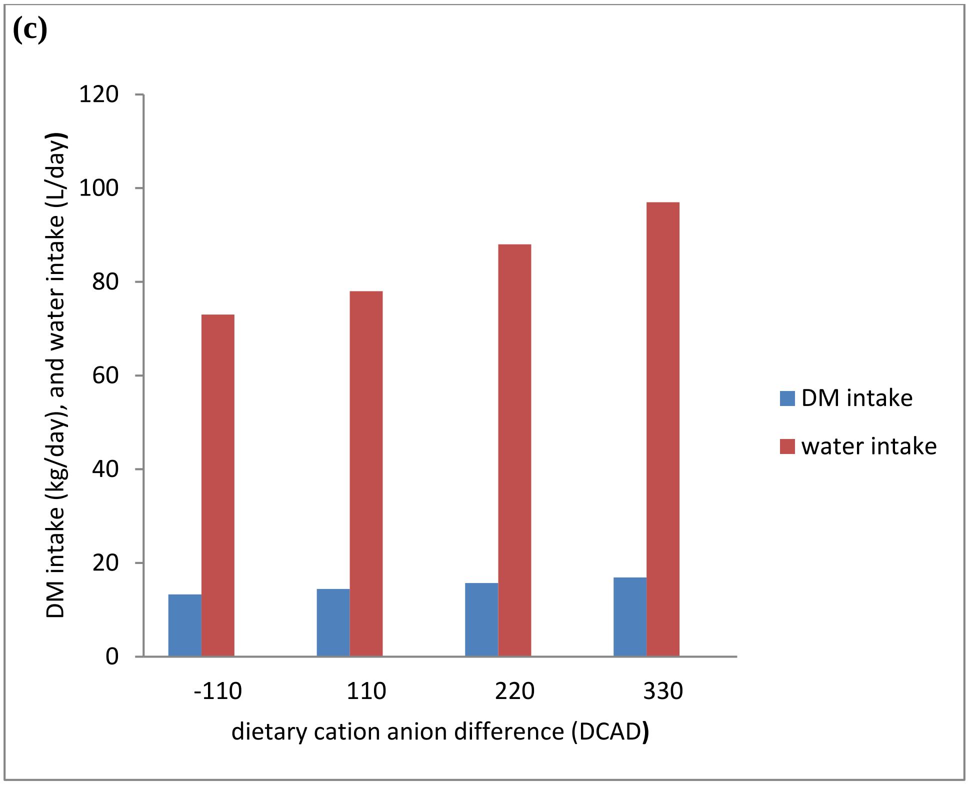
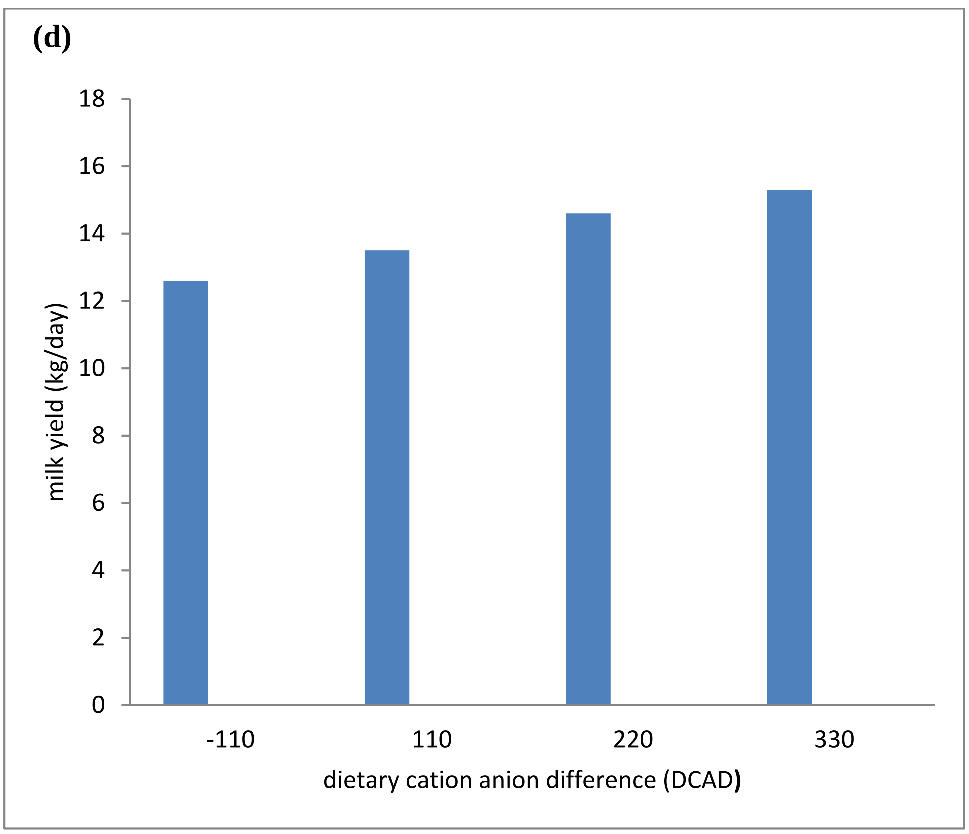


Fig. 2. Dry matter intake (DMI) and milk yield in shaded cow access to 0,1.3,4.9L/min intermittent sprinklers above the feed bunk


(a)
blood pH
7.6
7.55
7.5
7.45
7.4
7.35
7.3
7.25
7.2
-110
110
220
330
dietary cation anion difference (DCAD)
(b)
Blood HCO_3
30
25
20
15
10
5
0
-110
110
220
330
dietary cation anion difference (DCAD)


(c)
DM intake (kg/day), and water intake (L/day)
120
100
80
60
40
20
0
-110
110
220
330
dietary cation anion difference (DCAD)
DM intake
water intake


(d)
milk yield (kg/day)
18
16
14
12
10
8
6
4
2
0
-110
110
220
330
dietary cation anion difference (DCAD)

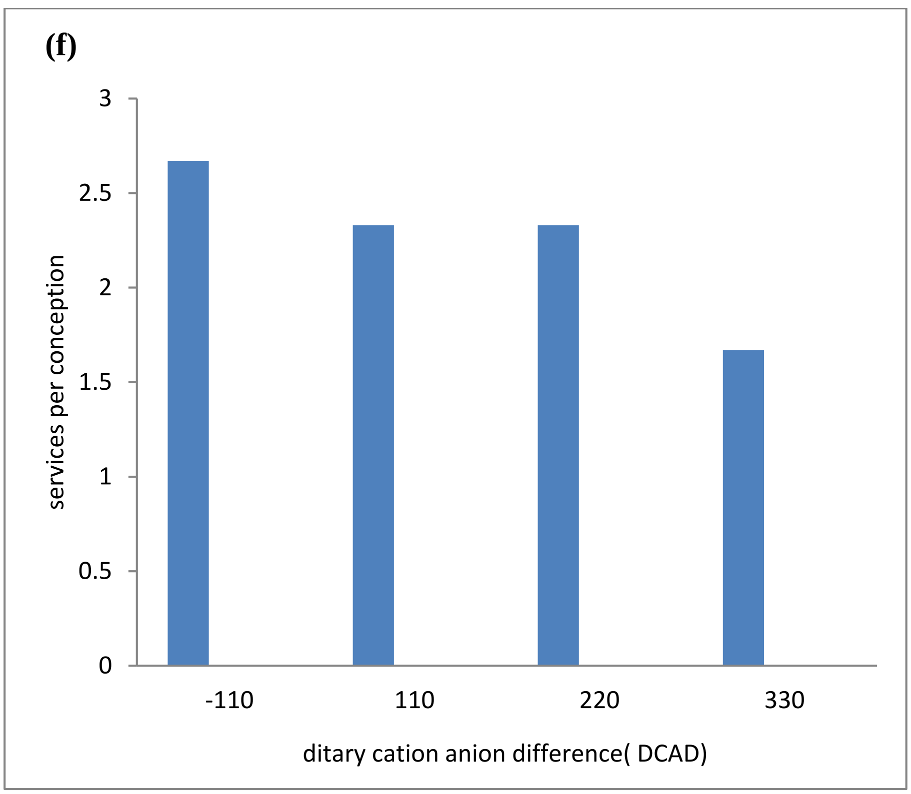


Fig.3. Influence of DCAD on (*a*) blood pH, (*b*) blood HCO_3, (*c*) DM and water intake, (*d*) milk yield services per conception, (*e*) conception rate in early lactating buffaloes and (*f*) services per conception of lactating buffaloes