Growth Promoters and Their Effects on Beef Production - Review -

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ABSTRACT : Application of growth promoters by means of implantation or supplementation to the diets has been routine in the beef cattle industry of many countries for the better performance in growth and improvement of feed efficiency. Anabolic implants (zeranol, trenbolone acetate, and estradiol with testosterone or progesterone) have generated various positive effects. Zeranol implantation, in general, improved average daily gain (ADG), feed conversion (FC), dressing percentage (DP) and yield grade (YG) of cattle, and increased dry matter intake (DMI). Trenbolone acetate with or without estradiol also increased mean values of ADG and loin eye area (LEA) but reduced DMI and improved FC of cattle. Estradiol with testosterone or progesterone increased ADG and DMI. Anabolic implants, however, had minimal or negative effects on marbling or quality grade. The magnitude of the response to these anabolic implants in performance of beef cattle has varied depending on the type of implants, amount and duration of exposure, age of animals and combination of implants. Administration of bovine somatotropin improved ADG and FC, and decreased fat deposition. Ionophores improved FC in cattle from reduced DMI without great response to ADG. Supplementation of monensin and lasalocid reduced molar proportion of propionate. Monensin and lysocellin increased apparent absorption and retention of some minerals in cattle. Despite the improved cattle performance in growth and FC, results in beef quality from the application of the growth promoters appeared to vary or in conflict under a variety of environmental conditions. *(Asian-Aust. J. Anim. Sci. 2001. Vol. 14, No. 1 : 123-135)*

Key Words : Growth Promoters, Beef Cattle, Growth, Feed Conversion, Carcass Characteristics

INTRODUCTION

Growth promoters have been widely applied to improve growth rate and feed conversion (FC) of beef cattle. Growth promoters are given to livestock either eith a drug delivery system, as injections or supplementation in the diet. The most extensively applied growth promoters are anabolic implants (both estrogenic and androgenic), bovine somatotropin (bST) and ionophores. Many studies have been conducted to evaluate the effects of these materials on performances and carcass characteristics of cattle, aspects of endogenous hormonal and metabolites. Anabolic implants, in general, are known to improve growth rates (GR) and feed efficiency (FE) with varied body compositions (Rusk et al., 1992; Mader, 1994; Herschler et al., 1995). Administration of bST also has improved GR and FE and reduced fat deposition in cattle (Moseley et al., 1992). Results from the studies explained that improved FE by ionophore feeding has been deroven from improved energetic efficiency in the cattle (Beede et al., 1986; Harvey et al., 1988; Delfino et al., 1988). Ionophores such as monensin (Kirk et al., 1985) and lysocellin (Kegley et al., 1991) are also known to affect the mineral metabolism in the body.

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EFFECT OF GROWTH PROMOTERS ON PERFORMANCES OF CATTLE

Anabolic implants

Synthetic anabolic implants have increased protein deposition, rate of gain, FE and retail carcass yield while decreased fat deposition in growing cattle. The magnitude of response, however, has been influenced by the age of animal, the duration of exposure to the implantation and the feeding environment. Various hormonal implants have been applied to beef cattle, but focus of this overview will be lain on zeranol, trenbolone acetate and estradiol with testosterone or progesterone, and will be summarized mainly on the aspects of performance, carcass characteristics and some endogenous metabolites in cattle.

Zeranol

Growth promoting effects of zeranol (resorcyclic acid lactone, Ralgro, Pitman-Moore, Mundelein, IL) implant have been investigated on the implantation at the phases of suckling (Mader et al., 1985), growing (Vanderwert et al., 1985) and finishing (Johnson et al., 1984) of beef production. Zeranol is known to effectively increase GR of beef cattle throughout the entire production cycle (Gray et al., 1986; Deutscher et al., 1986; Simms et al., 1988). Overall mean values of pooled data indicate that zeranol increased average daily gain (ADG) and dry matter intake (DMI), and improve feed conversion (FC) in bulls and steers (table 1).

Results from the most studies revealed that zeranol implanted cattle at growing and (or) finishing phase had improved weight gain 4 to 15% (Williams et al., 1987; Egan et al., 1993; Mader, 1994) and FC by 3 to 8% (Price and Makarecien, 1982; Greathouse et al., 1983; Egan et al., 1993). Recent study by Smith et al. (1999) indicated an improvement in ADG for 42 d by 3.4% from zeranol implanted Holstein veal calves compared to non-implanted ones. Re-implantation of zeranol, in general, have enhanced growth performance (Loy et al., 1988; Deutscher et al., 1986). The response of zeranol implantation to the cattle performance, however, has been inconsistent. Zeranol implantation at suckling periods had no advantages in growth performance during pre-weaning period (Mader et al., 1985), and growing and finishing phases (Simms et al., 1988). Silcox et al. (1986) and Gray et al. (1986) also reported no response of zeranol to the cattle performance.

Zeranol implantation also increased the average values of carcass weight (CW), backfat thickness (BT) and yield grade (YD) by 2%, 13.4% and 6.0%, respectively but had little effect on dressing percentage (DP) and loin eye area (LEA), and kidney, pelvic and heart (KPH) fat contents of bulls and steers compared with those of non-implanted cattle (table 1). Varied effects were, however, observed from a each study. Zeranol has increased hot CW (Gray et al., 1986; Calkins et al., 1986), DP (Greathouse et al., 1983; Vanderwert et al., 1985), BT (Unruh et al., 1986; Calkins et al., 1986), LEA (Silcox et al., 1986; Simms et al., 1988) and YG (Greathouse et al., 1983; Williams et al., 1987) over non-implanted cattle. However, some results exhibited decreased values in DP (Calkins et al., 1986), BT (Vanderwert et al., 1985), LEA (Gray et al., 1986) and YG (Calkins et al., 1986). Response of zeranol to carcass quality of beef cattle is also inconsistent. Results indicated improved marbling scores (Unruh et al., 1986) and palatability (Greathouse et al., 1983) or no response (Johnson et al., 1984; Paisley et al., 1999).

Zeranol has some estrogenic effects. The mechanism by which estrogenic substances increase growth seems to involve an indirect action on the pituitary that causes the release of ST (Grigsby and Trenkle, 1986) and a direct action on skeletal muscle receptors (Preston, 1987).

Trenbolone acetate

Trenbolone acetate (TBA, Finalix®, Hoechst Roussel, North Somerville, NJ) is a potent synthetic analogue of testosterone (Velluz et al., 1967) which is thought to act on skeletal muscle, either through androgen receptors to increase protein synthesis or through glucocorticoid receptors to reduce the catabolic effects of glucocorticoids (Muir, 1985). Implants of estrogen or a preparation of estrogens and androgens are practically used in steers, veal calves and bulls, whereas androgenic preparations such trenbolone are used in heifers and cows.

Implantation of TBA alone appeared to reduce overall mean values of DMI and FC of cattle (steers, bulls and heifers) by 9.8% and 11.2%, respectively but slightly increased ADG compared to those of non-implanted cattle (table 2). Implantation of TBA in combination with estradiol (E_2) also reduced the overall mean values of DMI and FC by 12.4% and

Table 1. Effect of zeranol implantation on growth performance and carcass of cattle*

Items	Control	Zeranol	Change %	No of cattle	
				Bull	Steer
Growth performance :					
Initial wt, kg	251.3	250.7	-	148	186
Final wt, kg	431.2	442.1	-	74	338
Average daily gain, kg	1.24	1.30	4.8	188	338
DM intake, kg/d	8.68	9.12	5.1	-	130
Feed/gain	6.56	6.30	-4.0	168	186
Carcass characteristics :					
Carcass wt, kg	304.0	310.0	2.0	222	222
Dressing, %	61.6	61.9	0.5	64	88
Backfat thickness, cm	0.82	0.93	13.4	182	190
Loin eye area, cm^2	81.6	82.3	0.9	154	154
KPH fat, %	2.31	2.30	-	154	154
Yield grade	2.32	2.46	6.0	150	222

* Overall mean values of pooled data from the following 10 published papers: Greathouse et al. (1983), Calkins et al. (1986), Gray et al. (1986), Vanderwert et al. (1985), Silcox et al. (1986), Unruh et al. (1986), Williams et al. (1987), Loy et al. (1988), Simms et al. (1988), and Bagley et al. (1989).

10.9%, respectively, and the ADG was even greater than implantation of TBA alone. Most studies have proved that both GR and FE in cattle were improved by single implantation of TBA (Apple et al., 1991) or combination of TBA with E_2 (Johnson et al., 1996; Foutz et al., 1997). Henricks et al. (1997) found that treatment of 200 mg TBA alone or 140 mg TBA with 14 mg E_2 improved ADG and FE by more than 10% without change in feed intake. Trenkle (1983) reported that when TBA and estrogenic compounds are used together they act independently, which results in an additive effect in feedlot finishing program. Herschler et al. (1995) suggested 200 mg TBA/28 mg E_2 dose for the optimal growth and FC in both heifers and steers.

The rate of degradation was reduced more than the rate of synthesis by androgenic TBA, thus increasing net protein deposition in muscle (Buttery et al., 1978). Muir (1985) also indicated that androgen increased carcass protein content of cattle by stimulation of muscle protein synthesis. Overall mean values from published papers (table 2) indicate that implantation of TBA lowered BT and YG by 3.6% and 4.7%, respectively but increased LEA and KPH fat content by 2.3 and 10.9%, respectively compared to control. Implantation of TBA in combination with E_2 also increased LEA but highly depressed KPH fat storage. Johnson et al. (1996) observed an increased BT from TBA with E_2 implanted cattle compared with non-implanted ones. Increased (Apple et al., 1991; Henricks et al., 1997) or reduced (Johnson et al., 1996) KPH fat content by implantation of TBA with or without E_2 was reported. Loin eye area, however, was generally promoted by implants (Johnson et al., 1996; Henricks et al., 1997). Despite the anabolic effect of estradiol with or without other implants on growth effects marbling or quality grade have been minimal (Owens et al., 1980; Turner et al., 1981; Perry et al., 1991) or reduced (Trenkle, 1990; Apple et al., 1991; Bartle et al., 1992).

Two delivery systems have been used in practice. Lactose is used preparing pellets because it is well absorbed by tissues and yields hard pellets (Keane and Sherington, 1985). Cholesterol has been used as another support because it appears to be absorbed and metabolized more slowly than lactose, allowing slower release of anabolic agents (Istasse et al., 1988).

Estradiol with testosterone or progesterone

Synovex (Syntex Agribusiness, West Des Moines, IA) is a synthetic analogue of steroid and consists of three combinations of estradiol benzoate and testosterone or progesterone. Synovex-C (10 mg estradiol benzoate and 100 mg progesterone) has been applied to both steer and heifer calves while Synovex-S (20 mg estradiol benzoate and 200 mg progesterone) and Synovex-H (20 mg estradiol benzoate and 200 mg testosterone propionate) for steers and heifer, respectively. Data from seven published papers relating to Synovex implants were summarized (table 3).

Growth performances of beef cattle varied with Synovex types. Synovex-C increased overall mean ADG and daily DMI of calves by 4%, thus resulted

Table 2. Implantation effects of TBA with or without estradiol E_2 on growth performance and carcass characteristics of cattle*

Items	Control	TBA	Change %	TBA+E_2	Change %	No of cattle		
						Steer	Bull	Heifer
Growth performance :								
No of cattle	309	119	-	191	-			
Initial wt, kg	289.5	260.6	-	319	-	462	24	133
Final wt, kg	4677	448.0	-	525	-	462	24	133
Average daily gain, kg	1.19	1.21	1.7	1.5	26.1	462	24	133
DM intake, kg/d	8.08	7.29	-9.8	9.08	-12.4	462	24	104
Feed/gain	6.79	6.30	-11.2	6.05	-10.9	466	8	96
Carcass characteristics :								
Carcass wt, kg	300	281	-	3.61	-	219	0	96
Dressing, %	61.8	62.4	1.0	61.7	0	446	8	80
Backfat thickness, cm	1.1	1.07	-3.60	1.12	0	446	0	109
Loin eye area, cm^2	75.3	77	2.3	80.1	6.4	446	0	109
KPH fat, %	2.64	2.93	10.9	2.18	-17.4	398	0	109
Yield grade	2.96	2.82	-4.7	3.02	2.0	398	0	96

* Overall mean values of pooled data from the following 10 published papers: Henricks et al. (1982), Basson et al. (1985), Gill et al. (1986), Faulkner et al. (1989), Crouse et al. (1987), Istasse et al. (1988), Rumsey and Harmond (1990), Garber et al. (1990), Apple et al. (1991), and Herschler et al. (1995).

in no improvement in FC. But ADG of steers and heifers were increased by implantations of Synovex-S and Synovex-H by 14.0% and 7.7%, respectively compared with non-implanted cattle. Because of differences between Synovex-S and Synovex-H in daily DMI (17.5 kg vs 2.7 kg), FC increased in Synovex-S implanted steers while reduced in Synovex-H implanted ones. The pooled data in growth performance were similar to the previous reports (Rusk et al., 1992) relating to the Synovex-C or Synovex-S implantations. Combined implantations of estradiol with progesterole or testosterone have improved rates of gain of beef cattle (Lemieux et al., 1988) and Holstein veal calves by 2.4 to 4.7% (Smith et al., 1999). Wilson et al. (1999) also found the increased carcass weight of Holstein veal calves from 3.3 to 3.9% as influenced by Synovex-H implantation. Donovan et al. (1983), Calkins et al. (1986) and Bartle et al. (1990) concluded that most implants were more effective in steers than in bulls.

Mean values of pooled data indicate increased BT, LEA and YG but decreased KPH fat by 15.67%, 5.07%, 6.25% and 7.14%, respectively in Synovex-S treated steers, while improved LEA but reduced BT, KPH fat and YG by 5.12%, 2.44%, 6.90% and 3.85%, respectively in Synovex-H implanted heifers (table 4). Decreased BT in heifers was also observed by Synovex-H (Reiling et al., 1996) or Synovex-C (Mader et al., 1994). KPH fat contents in steers and heifers were also reduced by Synovex implants compared with non-implanted cattle (Mader et al., 1994; Gerken et al., 1995).

An effect of Synovex implant bave been influenced by the dietary regime. As intake of a given diet was reduced from near ad libitum to a submaintenance level, response to Synovex-S became negative (Oltjen et al., 1973; Rumsey and Hammond, 1990). Thus, response to Synovex would be expected to be sensitive to both dietary protein and energy intake. Rumsey et al. (1999) concluded that adequate dietary protein is necessary to optimize the response to estrogenic growth promoters and that the low response under inadequate protein and energy intake is not improved by increasing the energy density of the diet.

Implants on reproductional traits

Various implants have influenced on reproductional activity of cattle. Implanting bulls with zeranol resulted in reduced testicle weights (Silcox et al., 1986; Bagley et al., 1989). The previous reports also indicated that zeranol suppresses testis development in bulls implanted during the pre-weaning growth period (Kiang et al., 1978) by inhibiting the activity of germinal epithelium and testosterone production by testis Leydig cells (Juniewicz et al., 1985). Juniewicz et al. (1985), however, reported that testicular growth and masculinity characteristics are not affected in bulls implanted with zeranol after weaning or as yearlings.

Table 3. Effect of Synovex implantation on growth performance of cattle*

Items	Control	Synovex	Change %	No of cattle	
				Heifer	Steer
Synovex-C :					
Initial wt, kg	122.5	131.5	-	238	192
Final wt, kg	396.0	408.5	-	238	192
Average daily gain, kg	1.09	1.14	4.6	238	192
DM intake, kg/d	9.23	9.65	4.6	238	192
Feed/gain	8.47	8.46	0	-	192
Synovex-S :					
Initial wt, kg	260.7	262.3	-	-	96
Final wt, kg	415.7	433.3	-	-	96
Average daily gain, kg	1.14	1.30	14.0	-	96
DM intake, kg/d	7.62	8.95	17.5	-	96
Feed/gain	6.68	6.80	1.8	-	-
Synovex-H :					
Initial wt, kg	281.0	276.0	-	184	-
Final wt, kg	449.0	467.8	-	236	-
Average daily gain, kg	1.17	1.26	7.7	284	-
DM intake, kg/d	8.80	9.04	2.7	284	-
Feed/gain	7.52	7.17	-4.7	-	-

* Overall mean values of pooled data from the following 8 published papers: Lemieux et al. (1988), Bartle et al. (1990), Rusk et al. (1992), Hancock et al. (1994), Mader (1994), Mader et al. (1994), Hardt et al. (1995), and Rumsey et al. (1996).

Table 4. Effect of Synovex implantation on carcass characteristics of cattle*

Items	Control	Synovex	Change %	No of cattle	
				Heifer	Steer
Synovex-S :					
Carcass wt, kg	315.0	329.5	4.60	-	84
Dressing, %	62.7	63.4	1.12	-	96
Backfat thickness, cm	1.34	1.55	15.67	-	84
Loin eye area, cm^2	71.0	74.6	5.07	-	96
KPH fat, %	2.80	2.60	-7.14	-	96
Yield grade	3.20	3.30	6.25	-	84
Synovex-H :					
Carcass wt, kg	270.7	283.5	4.73	248	-
Dressing, %	59.6	59.9	0.50	200	-
Backfat thickness, cm	1.23	1.20	-2.44	248	-
Loin eye area, cm^2	74.2	78.0	5.12	248	-
KPH fat, %	2.90	2.70	-6.90	156	-
Yield grade	2.60	2.50	-3.85	156	-

* Overall mean values of pooled data from the following 5 published papers: Hancock et al. (1994), Mader et al. (1994), Gerken et al. (1995), Reiling et al. (1996), and Samber et al. (1996).

Kniffen et al. (1999) also observed the retarded reproduction function by early and continuous implantation of heifers with estradiol.

Meanwhile, zeranol implants in heifers have increased pelvic area at weaning or breeding (Staigmiller et al., 1983; Deutscher et al., 1986). However, implants may not be applied to heifer calves because of possible detrimental effects on subsequent fertility. Staigmiller et al. (1983) observed a trend toward lower conception rates among heifers implanted as calves. The effect of implantation on reproduction may rely on the nutritional status. Deutscher et al. (1986) reported that heifers fed a high nutritional level tended to reach puberty at higher total conception rate than implanted heifers on the regular nutritional level. Implanting dam with zeranol increased calving ease.

Effect of anabolic implants on endogenous hormones and blood metabolites

Actions of anabolic implants may alter various hormonal secretions of the pituitary and other endocrine glands. Anabolic agents with estrogenic activity mediated their growth promoting effects by altering circulating concentrations of endogenous ST and (or) insulin in steers (Muir, 1985) and in bulls (Gray et al., 1986). But estrogenic agents such as estradiol-17β have elevated plasma triiodothyronine and thyroxine concentration by zeranol in cattle (Gopinath and Kitts, 1984). Henricks et al. (1982) observed that plasma estradiol-17β rose to over 7.5 pg/ml in response to TBA (30 mg) implantation. Implantation 120 mg TBA in combination with 24 mg estradiol also increased circulating trenbolone and E_2 concentrations in crossbred steers (Johnson et al., 1996). Henricks et al. (1997) also found the increased serum trenbolone-17β concentration in heifers by 200 mg TBA implantation. Plasma IGF-I concentrations were greater in implanted (14 m mg TBA+28 mg estradiol-17β) steers than in control ones (Hongerholt et al., 1992). Johnson et al. (1998) reported that combined implants of TBA with E_2 increased the IGF-I production by muscle tissue, and they postulated that increased local IGF-I levels may provide a possible mechanism for the increased muscle growth because IGF-I is an extremely potent anabolic agent for skeletal muscle. It has been reported that overall concentrations for serum albumin and plasma urea, and greater N retention were reduced in heifers by implantation of TBA (Galbraith, 1980).

Bovine somatotropin

There has been an increasing interest in use of bovine somatotropin (bST) as a potential growth stimulator. Mean values of pooled data from 8 reported papers clearly indicate that bST improves ADG and FC in cattle (table 5). Early et al. (1990a) reported that bST administration (20.6 mg/d/head) to steers increased weight gains 15% and FE 12% compared with non-treated steers. Animals treated with bST (20.6 mg/d) gained faster and were heavier between 12 and 15 month of age than non-treated heifers (McShane et al., 1979). Similar effects were observed from the bST treated steers and heifers (Tripp et al., 1998). Moseley et al. (1992) also reported from trials (0 to 300 ug/kg BW/d in trial 1 and 0 to 66 ug/kg BW/d in trial 2) that growth performance of steers receiving bST was dose-dependent; ADG changed linearly, DMI decreased

Table 5. Effect of bovine somatotropin (bST) administration on cattle performance*

Items	Control	Synovex	Change, %	No of cattle
Growth performance :				
No of steers	154	317	-	-
Initial wt, kg	381.5	391.9	-	-
Final wt, kg	529.6	544.9	-	-
DM intake, kg/d	8.73	8.49	-2.75	-
Average daily gain, kg	1.22	1.31	+7.38	-
Feed/gain	7.16	6.48	-9.50	-
Carcass characteristics :				
Carcass wt, kg	329	336	-	467 s
Dressing, %	60.9	61.1	+0.33	467 s
Loin eye area, cm^2	74.0	78.8	+6.49	416 s
Backfat thickness, cm	0.50	0.48	-4.00	416 s+128 h
KPH fat, %	3.27	2.59	-20.8	151 s

* Overall mean values of pooled data from the following 9 published papers: Peters (1986), Enright et al. (1990), Hancock and Preston (1990), Early et al. (1990a), Early et al. (1990b), McShane et al. (1979), Moseley et al. (1992), and Dalke et al. (1992).

linearly, and FE changed quadratically. Dose-dependent manner in both DMI and FE of steers responded to bST injection was also reported although its dosage did not affect ADG or final weight of steers (Dalke et al., 1992).

Treatment of bST appeared to increase DP and LEA, and reduced BT and KPH aft content in steers and heifers (table 5). According to Early et al. (1990b), ratios of CP to ether extractable fat in the total body were greater but DP was lower in bST steers. Wagner et al. (1988) also observed increased carcass protein and decreased carcass fat deposition in steers administered 960 mg of bST subcutaneously every 14 d. Heifers treated with bST (20.6 mg/d) had less BT than non-treated ones (McShane et al., 1979). Administration of bST altered carcass composition by increasing carcass protein and decreasing carcass fat (Moseley et al., 1992). Bovine ST decreased BT, marbling score and quality grade, and increased YG in a linear dose-dependent manner.

Despite the magnitude of the response to the bST has been substantial, it seems to depend on management conditions within the study (Grings et al., 1990). As well, the anabolic effect of bST could be related to a change in total ST secretion, the frequency or height of ST spikes, or the magnitude of the change in basal concentrations of serum ST (Moseley et al., 1982). Body weight gain by exogenous administration of ST seems to be the N retention (Hancock and Preston, 1990). Moseley et al. (1982) found that treatment of Holstein steers with exogenous ST (48 ug/kg BW) increased the apparent digestion coefficients for dietary N and N retention, and metabolizable N. Hancock and Preston (1990) had a reduced plasma urea N (PUN) in a dose dependent manner of bST in growing steers.

Ionophores

Ionophores are compounds that form lipid soluble complexes with certain cations, and facilitate their transport across biological membranes (Pressman et al., 1980). The most widely accepted ionophores are monensin, lasalocid and lysocellin. Focus relating to the supplemental effects of ionophores will be placed on the growth performance, feed utilization including alterations in the ruminal volatile fatty acids (VFA), nutrient digestibility and protein utilization.

Monensin

Monensin (Rumensin) is a biologically active compound produced by the fungus *Streptomyces cinemonsis*, and classified as an ionophore because it facilitates transport of monovalent cations across membranes (Pressman, 1976). Monensin has been widely accepted by the cattle feeding industry since it was approved in 1975. The effects of monensin supplementation to the diets on various cattle performances were well overviewed by Goodrich et al. (1984), and will be summarized again based on the reports of Goodrich et al. (1984) because only a few researches have conducted the experiments since 1984.

Monensin supplementation has resulted in improved FC, mainly due to the reduced DMI as its response in ADG is small in cattle (Goodrich et al., 1984, table 6). Results of other studies confirmed that monensin in diet reduced DMI and improved FE without adversely affecting growth rate (Beede et al., 1986). Feed intake and FC of cattle were reduced in a dose-dependent manner when monensin was supplemented to the diets at different levels (Goodrich et al., 1984). Previous results concerning to the monensin supplementation in ADG and feed intake were proved by the recent study (Rogerio et al., 1997). They observed an improved ADG of Holstein steers fed monensin supplemented diet and the effect was increased by high quality protein diet.

Reduced consumption of diet, but similar growth rates of monensin fed cattle to the cattle fed non-supplemented diet indicate that monensin increase an efficiency of energy (E) utilization. Wedegaertner and Johnson (1983) reported that metabolizable E (ME) utilization was increased from 63.3 to 66.8% of gross E intake by monensin, and both NEm and NEg were improved by approx. 7% by monensin. Byers (1980) also reported that monensin improved NEg values (1.20 vs 1.32 Mcal/kg) more than it improved NEm values (1.66 vs 1.70 Mcal/kg) of the diets. Fasting heat production was reduced slightly (83.5 vs 79.5 kcal/$W^{0.75}$) when monensin was included in the diet (Garrett et al., 1980).

Monensin is effective in altering the rumen fermentation to one of a higher molar proportion of propionate (C_3), and these alterations have been implicated as the primary response factor responsible for the increased FE (Rechardson et al., 1976). As shown in table 7, the monensin feeding resulted in increased ruminal C_3 concentrations (Zinn and Borques, 1993; Vagnoni et al., 1995; Domescik and Martin, 1999). Pooled data indicate the reduced VFA production and molar percent of butyrate by 7.7% and 20.2%, respectively by the monensin feeding (table 8). Vagnoni et al. (1995) also found reduced total VFA concentration. Dinius et al. (1976), however, could not observe any change in total VFA concentration by the monensin feeding.

Monensin may spare dietary protein from ruminal degradation. Poos et al. (1979) observed an increased dietary N passage from the rumen when monensin was fed ruminal ammonia concentration was reduced (Hanson and Klopfenstein, 1979) and glucogenic amino acids were conserved by increasing availability of C_3 for glucose synthesis (Raun et al., 1976) by monensin feeding. Dinius (1978) also reported that monensin increased escape of ruminal protein degradation with increasing protein solubility. The idea that monensin could spare protein or amino acids was supported by the observation that monensin decreased the specific activity of deamination and increased bacterial protein (Lana and Russell, 1997). An effect of monensin on digestibility of the diet has been controversial although summarized data had improved whole tract digestibility of DM, crude protein (CP) and fiber (table 7). No differences in digestibility of DM (Berger et al., 1981), fiber (Beede et al., 1986) and N (Morris et al.,

Table 6. Effect of monensin feeding on the performance of cattle*

Items	Control	Monensin	Change, %
Monensin intake, mg/d	0	246	
Initial wt, kg	284	283	
Final wt, kg	430	432	
Average daily gain, kg	1.09	1.10	1.6
DM intake, kg/d	8.27	7.73	-6.4
Feed/gain	8.09	7.43	-7.5

* Data were abstracted from the review of Goodrich et al. (1984).

Table 7. Effect of monensin feeding on ruminal VFA production and whole tract digestibility of diet*

Items	Control	Monensin	Change, %
Monensin intake, mg/d		150-276	
VFA production :			
Total VFA, mM	86.9	81.6	-6.1
Molar percents, mmol/100 mol :			
Acetate (C_2)	67.9	62.7	-7.7
Propionate (C_3)	20.4	27.7	35.8
Butyrate	9.9	7.9	-20.2
C_2/C_3	33.3	26.3	-32.1
Whole tract digestibility, % :			
DM	57.8	69.6	2.65
CP	57.8	62.3	7.79
NDF	53.1	55.7	4.95

* Overall mean values of pooled data from the following 7 published papers: Richardson et al. (1976), Raun et al. (1976), Perry et al. (1976), Dinius et al. (1976), Randall et al. (1978), Prange et al. (1978), and Morris et al. (1990).

Table 8. Effect of lacalocid feeding on cattle performance*

Items	Control	Lacalocid	Change, %
No of cattle	150	229	
Lacalocid intake, mg/kg DM/d	0	24-54	
Initial wt, kg	273.6	273.0	
Final wt, kg	473.8	481.0	
Average daily gain, kg	1.25	1.31	4.8
DM intake, kg/d	8.50	8.42	-0.9
Feed/gain	6.88	6.49	-5.7

* Overall mean values of pooled data from the following 5 published papers: Berger et al. (1981), Spears and Harvey (1987), Zinn (1987), Delfino et al. (1988), and Morris et al. (1990).

1990) were obtained by monensin intake. However, Wedegaertner and Johnson (1983) reported that monensin (3 mg/kg $BW^{0.75}$) improved apparent digestibility of E, neutral detergent fiber and CP in steers at equalized gross E intakes.

Monensin has been known to be effective in suppressing clinical infections of coccidian in cattle. Coccidiosis is most frequently observed in feedlot calves 6 to 9 month of age (Fitzgerald, 1975). Fitzgerald and Mansfield (1973) reported that monensin in pelleted feed at the level of 0.25 to 2.0 mg/kg BW/d protected 10 week old coccidian-inoculated calves from clinical signs of coccidiosis. Stockdale and Yates (1978) also found that monensin inoculated calves at a rate of 1 mg/kg BW/d suppressed clinical signs of coccidiosis from d 10 to 20 after inoculation. This was proved by Berger et al. (1981) in which monensin reduced the incidence and concentration of coccidian oocysts, and improved feed efficiency.

Lasalocid

Lasalocid is also one of the ionophores and has been applied to the beef cattle to improve FE. Pooled data indicate an increased ADG by 4.8% without affecting DMI, resulting in reduced FC as influenced by lasalocid feeding (24 to 54 mg/kg diet, DM/d, table 8). But a few studies (Spears and Harvey, 1987; Delfino et al., 1988) reported better weight gain of steers and heifers, while the other reports indicated reduced weight gain (Zinn, 1987) or no effect (Morris et al., 1990). Feed intake, in most, was not affected by lasalocid feeding.

Beneficial effect of lasalocid supplementation to the diets may be derived from the improved efficiency in E utilization. Delfino et al. (1988) reported that lasalocid improved ME density of the diets and NEm value of the diet was increased by 10 to 21% with lasalocid without affecting the NEg value. Average heat production of the steers was increased by 7% with lasalocid. Thus, they concluded that improved FC with lasalocid was by increasing the ME density of the diet.

Table 9. Effect of lasalocid feeding on VFA production and digestibility of diet*

Items	Control	Lasalocid	Change, %
Lasalocid in diet, mg/kg	0	33	
Ruminal VFA production :			
Total VFA, mM	111.50	114.40	0.3
Molarpercents, mmol/100mol :			
Acetate (C_2)	54.00	53.10	1.7
Propionate (C_3)	30.70	34.40	12.1
Butyrate	11.70	9.50	-18.8
C_2/C_3	1.96	1.61	-17.9
Whole tract digestibility, % :			
DM	79.70	79.60	0
CP	69.50	71.90	3.5
NDF	96.80	96.70	0.1

* Overall mean values of pooled data from the following 4 published papers: Spears and Harvey (1987), Zinn (1987), Delfino et al. (1988), and Morris et al. (1990).

Feeding of lasalocid, most likely to the monensin, decreased the rumen C_2/C_3 ratio with no difference in total VFA concentration (table 9). But the reduced ration was primarily to the increased molar proportion of C_3 as that of C_2 was not affected. Molar proportion of butyrate from lasalocid-fed cattle was greatly reduced compared with non-fed cattle. However, decreased (Spears and Harvey, 1987) or increased (Morris et al., 1990) molar proportion of C_2 by lasalocid feeding was reported. Lasalocid has also been known to reduce a methane production in the rumen. A reduction in methane production was reported in *in vitro* studies with lasalocid (Fuller and Johnson, 1981). Digestibility of diet may not be affected by lasalocid feeding (table 9) although Zinn (1987) reported increased whole tract digestibilities of organic matter and CP.

Lysocellin

Lysocellin is a carboxylic ionophore that differs from the commonly used ionophores (monensin and lasalocid) in its affinity for various ions (Painter and Pressman, 1985). Inclusion of lysocellin has improved performance of both growing and finishing cattle (Cain, 1987; Harvey et al., 1988) and reduced feed intake, resulting in improved FC in beef cattle (Wolfrom and Baldwin, 1986; Harvey et al., 1988). Estimated mean values revealed that DM intake and FC of cattle were reduced by 5.2% and 7.4%, respectively without being affected in ADG by lysocellin (11 to 33 mg/kg diet, DM/d) feeding (table 10). However, ADG was increased (Spears et al., 1989) or decreased (Kegly et al., 1991) by lysocellin supplementation. As lysocellin level increased from 11 to 33 mg/kg diet there was a linear decrease in DMI and an improvement in FC (Harvey et al., 1988).

Improved FE from lysocellin feeding may be related to altered VFA production in the rumen. Addition of lysocellin to the diets produced alterations in ruminal VFA that are similar to monensin and lasalocid (Spears et al., 1989; Sticker et al., 1991). Spears et al. (1989) reported that lysocellin (100 or 200 mg/d) improved FC and molar proportions of C_3, iso-butyrate and iso-valerate but decreased total VFA concentrations, molar proportion of C_2 and C_2/C_3 ratio.

Table 10. Effect of lysocellin feeding on cattle performance*

Items	Control	Lysocellin	Change, %
No of cattle	40	64	
Lysocellin intake, mg/kg DM/d	0	100~200	
Initial wt, kg	242.5	242.1	
Final wt, kg	324.5	324.3	
Average daily gain, kg	0.75	0.75	0
DM intake, kg/d	6.01	5.70	-5.2
Feed/gain	8.93	8.27	-7.4

* Overall mean values of pooled data from the following 5 published papers: Wolfrom and Baldwin (1986), Spears et al. (1989), Kegley et al. (1990), Kegley et al. (1991), and Sticker et al. (1991).

Molar proportion of C_2 was lower and C_3 was higher for the steers fed lysocellin (11 to 33 mg/kg diet, Harvey et al., 1988) than for the non-fed control animals.

Ionophores on mineral metabolism

Researches have been conducted on the metabolic and performance effects of varying mineral levels when fed with the ionophores. Ionophores such as monensin and lasalocid alter ion transport across cell membranes (Painter and Pressman, 1985). Monensin increased apparent absorption and retention of K, Mg and P (Starnes et al., 1984; Kirk et al., 1985). The efficacy of monensin is thought to be related to changes induced in the permeability of membranes to the selective cations (Pressman, 1976). Pressman (1976) reported that monensin has a strong affinity for Na, and K, increasing the K concentration outside the cell. Smith and Rozengurt (1978) also reported an increased activity of the Na-K pump by monensin.

Changes in mineral metabolism have been reported in a number of studies with lysocellin (Harvey and Spears, 1987; Spears et al., 1989; Kegley et al., 1991). Kegley et al. (1991) reported that lysocellin (22 mg/kg diet) increased apparent absorption of Mg and Ca but did affect concentration of several minerals in ruminal fluid and blood plasma. Spears et al. (1989) also reported that percent absorption of Ca, K, Mg and P was higher, whereas Na absorption was lower in steers fed lysocellin than in controls.

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