Phosphorus supplementation to grazing beef cows in the Molopo region (Saratoga) of the North-West Province

by

Theunis Cornelius Wessels

In fulfilment of the requirements for the degree Master of Science in Agriculture

in

The Faculty of Agriculture
Department of Animal Science
University of the Orange Free State
Bloemfontein

Supervisor: **Prof. H.O. de Waal**
University of the Orange Free State
Co-supervisor: **Prof. H.J. van der Merwe**
University of the Orange Free State

Bloemfontein, July 1999

Acknowledgements

To our Heavenly Father, God the Almighty, thankfulness for His mercy and granting the opportunity, health and strength to complete the work.

The author is also indebted to:

Prof. H.O. de Waal, the supervisor of this study and my mentor, for being such an outstanding example of passion, integrity, and commitment, thank you for being a light in leading me through this study. I am also grateful to be privileged to have shared in his experience in this field of animal science;

Prof. H.J. van der Merwe, the co-supervisor of this study, for his special interest in the study and valuable assistance, advice and guidance;

Mr. M.D. Fair of the Department of Datametrics (U.O.F.S.) for his advice and support regarding the statistical analysis of the data;

Dr. H.P. Spangenberg from whom I have learned so much and I acknowledge you for your participation in this study, I am eternally grateful;

Dr. W.D. Basson of Kynoch Feeds (Pty) Ltd is thanked for his donation of the commercial lick used in this trial;

the personnel of the Animal Science Division at Glen for their involvement in the study and especially:

Mr. J.M. Smith for the bone biopsies that were applied in this study and for his constant and skilled technical assistance during the trial;

Messrs. M.J. van den Heever (Extension officer) and H.P.J. Scholtz (Assistant Director

Extension) of the Department of Agriculture, Vryburg, for their commitment and input at Saratoga, which aided in the completion of this study;

Mr. J.A.J. van Eck, Head of the Pasture Science Division at Armoedsvlakte, for his help and classification of the plant material during the trial;

Mr. Erich and Mrs. Anne Graupner, whose farm we used for this trial, thank you for your vision, constant help and support in executing this on-farm trial;

the farmhands at Saratoga for their help and assistance;

the Bursary Committee (U.O.F.S.), through the Dean (Prof. P.I. Wilke) of the Faculty of Agriculture (U.O.F.S.), for the grant of the "May and Stanley Smith Charitable Trust" for the financial support;

Mrs. H.M.F. Linde and R. Barnard for their help and assistance with the typing;

my parents, family and friends for their sustained interest and support.

DECLARATION

I hereby declare that this dissertation submitted by me to University of the Orange Free State for the degree, **Magister Scientiae Agriculturae**, is my own independent work and has not previously been submitted by me at another University. I furthermore cede copyright of the dissertation in favour of the University of the Orange Free State.

Theunis Cornelius Wessels

Bloemfontein

July 1999

Contents

Table of contents

Chapter 1

General introduction

1. General introduction

About 65 million hectare (ha) veld (natural pasture), or 80% of the land area in South Africa is available for agricultural purposes and can only be effectively utilised by grazing ruminants (De Waal, 1990). The South African veld types are diverse in terms of botanical composition (Acocks, 1988), dry matter (DM) production potential and quality of the available DM (De Waal, 1994b). These variations are further exacerbated by differences in seasonal rainfall as well as its distribution. Variation in rainfall and the quantity and quality of the veld are characteristic of the arid and semi-arid areas of South Africa and occur at any site between years and are reflected in animal performance (De Waal, 1990; Van Niekerk, 1994). The grazing ruminant, therefore, exits in a highly dynamic situation where its performance in terms of growth, production and reproduction is determined not only by changes in nutrient requirements, but also by the physical environment, as well as quality and quantity of available pasture (Reid & Jung, 1982). Therefore, to maintain the livelihood of many South African farmers and especially those farming with beef cattle under these conditions may necessitate supplementary feeding to sustain animal production and reproduction. However, to be economically justifiable, supplementary feeding must be provided judiciously (Spangenberg, 1997).

According to De Waal (1998, personal communication) the statement above, namely that it may be necessary to provide supplementary feeding to grazing ruminants on veld, presupposes that their is a deficiency of some nature. In the past few decades, supplementary feeding of grazing ruminants in South Africa was elevated to the level of being perceived to be a fine art. The roots of some of the current supplementary feeding strategies may still be found in research programs that may be regarded as atypical of the free ranging situation. For instance, the inherent grazing behaviour of ruminants and the effect it may have on the diet that is selected, is still not widely accepted. There is no doubt that phosphorus (P) may play an important role in achieving improved levels of animal production (Theiler, 1920). However, it should be recognised that the recommendations regarding P supplementation cannot be the same everywhere in South Africa and also not be the same for cattle and sheep. Therefore, it is of utmost importance to increase our understanding of the role of P nutrition in animal production (reproducing beef cows) in a specific area in the Northwestern part of South Africa.

Four basic interdependent factors determine the amount of minerals in crops and forage plants, namely the plant species, the stage of maturity of the plants, the type of soil and the seasonal or climatic conditions during growth (Underwood, 1981). A fifth factor can be added, namely the influence of humans through livestock production management policies. Phosphorus deficiency is frequently associated with deficiencies of protein and energy (Gartner *et al.*, 1980) and is predominantly experienced by grazing ruminants. It occurs throughout the world and is mostly the result of a combination of soil and climatic effects on herbage P concentrations (Spangenberg, 1997). Therefore, herbage with subnormal P content is produced on soils low in plant-available P. Whole plant P content falls steeply with advancing maturity and long dry periods will result in low herbage P over lengthy periods, especially if herbage P concentrations are initially low (Underwood, 1981).

The basic goal of a supplementation program at a specific site should be to provide the nutrient which is limiting production and/or reproduction and this should be based on knowledge of the degree of limitation (Spangenberg, 1997). This limitation is largely influenced by season, while the quantitative requirements will depend on the extent of the limitation, the type of animal involved and its physiological or productive state. Although some of these factors may be manipulated by man to the advantage or perhaps the disadvantage of grazing ruminants (De Waal, 1994b), they remain important constraints for beef cattle production from veld (Hodgson, 1982). This may also be compounded by injudicious use of specific nutrients like sodium (Na) (De Waal, 1994a) or deficiencies of specific nutrients like P (Read *et al.*, 1986a).

At the turn of the century, the pioneering work by Sir Arnold Theiler (Theiler, 1912) and more recent work by Read *et al.* (1986b,c,d) have identified P as a major limiting nutrient for reproducing beef cattle at Armoedsvlakte (see later Figure 2.1) near Vryburg. As a result of the extraordinary response to P supplementation demonstrated by Theiler (1920), these findings were extended to the rest of South Africa and beyond. As a consequence, natural pastures in South Africa are generally considered to be P deficient and the supplementation of P became an integral part of animal production in Southern Africa (Theiler & Green, 1932; Du Toit *et al.*, 1940; Bisschop, 1964; Shur, 1968; Ward, 1968; Louw, 1969; 1978; 1979; Groenewald, 1986; Van Niekerk, 1994).

Although later studies confirmed a P deficiency in grazing cattle at Armoedsvlakte (Read *et al.*, 1986b,c,d; De Waal *et al.*, 1996; De Waal & Koekemoer, 1997), several studies elsewhere in South Africa failed to show beneficial effect to supplementary P, namely with sheep at Glen in the central Orange Free State (De Waal *et al.*, 1981; De Waal & Biel, 1989a,b), Upington (Faure *et al.*, 1985), Koopmansfontein (H.O. de Waal, E.A.N. Engels, A. Malan, H. Terblanche & M.A. Baard, 1987; unpublished data), Carnarvon (Marais *et al.*, 1989) and with cattle at Glen (Read *et al.*, 1986b,c,d), Tierhoek (Rouxville district; H.O. de Waal, H.P. Spangenberg, C. Van Rooyen & J.M. Smith, 1991; unpublished data) and Vaalharts (Spangenberg, 1997).

Although P was defined in some local studies as the limiting nutrient for grazing ruminants, it is considered globally to be the most common mineral deficiency in cattle (McDowell *et al.*, 1984). An important test or criteria for such a limiting nutrient would be an improved performance in response to its supplementation (Read *et al.*, 1986b), such as the dramatic increase in animal production which resulted from supplementary P in trails at Armoedsvlakte (Theiler & Green, 1932; Read *et al.*, 1986a,b; De Waal *et al.*, 1996). Therefore, P was considered the first limiting nutrient in the renewed research program on supplementary feeding to grazing cattle that commenced in the erstwhile Free State Region (Spangenberg, 1997) after the classical work of Theiler (1912).

The influence of the livestock producer on the utilisation of pastures, which in most cases is the sole source of food under extensive grazing conditions, must be considered (Spangenberg, 1997). The livestock producer should acknowledge the limitations of nature in terms of rainfall and the quantity and quality of the veld on animal production through sound management practices. Taking into account the erratic rainfall pattern and consequently that of veld quality in South Africa, it is important that the livestock producer must give specific attention to these given and non-controllable factors (Spangenberg, 1997). Although diet quality is important and an essential factor, production by the grazing ruminant is more dependant on the total daily intake of digestible nutrients (Hodgson & Rodriguez, 1971). The essential part is this statement being the intake of digestible nutrients per unit of time and not the quality of the diet *per se* (1998, H.O. de Waal, personal communication). Considering the quality of the herbage selected by ruminants through their selective grazing behaviour, reasonable levels of animal production may be expected even during winter, provided that intake is not impaired or nutrient requirements imposed by physiological status such as growth or lactation voluntary are not too high (De Waal, 1990). Therefore, by synchronising animal production according to the limitations imposed by nature on production and reproduction, it could be possible to minimise and under certain conditions even eliminate some of the practises of supplementary feeding (Spangenberg, 1997).

The depressive effect of aphosphorosis on reproductive ability is one of the most striking results (Hemingway, 1967, as cited by Read, 1984). In the trial by De Waal *et al.* (1996), the existence of a P deficiency in grazing cattle at Armoedsvlakte was confirmed once again and three levels of P supplementation, as well as the duration of supplementation that had been provided, created a gradient of animal performance and financial returns. Read (1984) concluded earlier that no consistent response to P supplementation was realised in any aspect of animal performance at Glen. This might be an indication that the pasture P content at Glen was, in contrast to Armoedsvlakte, sufficient to prevent any visible symptoms of a P deficiency, which may have affected animal performance, even in the unsupplemented treatment. According to the results of a P trial with cattle on the western highveld of South Africa, no differences in calving and weaning percentages occurred between treatment groups (De Brouwer *et al.*, 1997, as cited by Spangenberg, 1997). This latter herd maintained a conception rate of 88% with a mating season of 63 days for the duration of the trial.

Read (1984), Read *et al.* (1986b), Groenewald (1986) and De Waal *et al.* (1996) came to the conclusion that there would seem to be a pattern in the conception, calving and weaning rate of cows in -P treatments, *i.e.* a considerable lower reproduction rate and calving every second year ("seesaw effect"). This is in agreement with the observations of Du Toit and Bisschop (1929, as cited by Read, 1984) that one or more barren years are required to build up skeletal reserves before pregnancy again occurs. No abnormalities of the reproductive tract or ovulation had been found by Theiler *et al.* (1937), despite the strong evidence of reduced reproductive performance in P deficient animals. A P deficiency *per se* may not affect the reproductive performance (Cohen, 1975). To consider the failure of production as one aspect only of a general deprivation of cellular P (MacDonald, 1968), it must always be taken into account that a P deficiency is accompanied by a concurrent reduction in herbage intake, which would lead to other nutrient deficiencies (Little, 1975). Malnutrition or underfeeding may lead to prolonged anestrus and where mating seasons of limited duration are applied, it would result in poor reconception (Elliott, 1964).

Read *et al.* (1986b) showed a 9.8% difference (34.0 kg vs. 37.7 kg) in average birth mass of calves and a 27.5% difference (231.8 kg vs. 181.8 kg) in the average weaning mass of calves from unsupplemented (-P) and supplemented (+P) cows at Armoedsvlakte. De Waal *et al.* (1996) reported minor differences for average birth mass and weaning mass of calves between treatments and within calving seasons. De Brouwer *et al.* (1997, as cited by Spangenberg, 1997) also reported that all the measured variables on calves were not significantly different between treatments. The reason for this apparently lies in the fact that the cow sacrifices most of her own body tissue to shield the calf from such deficiencies, ensuring the existence of the species. According to Read (1984), this is particularly true towards the end of pregnancy, where large changes in body mass of the dams occurred, indicating that the dam sacrifices herself for the calf *in utero*. De Waal *et al.* (1996) stated that the tendency for the treatments that received low P levels in their trial at Armoedsvlakte to wean lighter calves, is probably an indication that there is a limit to which body reserves of the cow can be utilised before having an effect on milk yield and the growth of the calf. Furthermore, according to De Waal *et al.* (1996) there appeared to be no advantage of P supplementation on the birth mass, weaning mass or average daily gain (ADG) of calves from birth to weaning, in contrast to the results of the earlier trials at Armoedsvlakte and Glen, as reported by Read *et al.* (1986b).

All deficiencies will sooner or later affect animal performance (growth, lactation, etc.), even though in some cases the appearance of the animal may not be affected to a great extent. Therefore, chemical analyses are essential in this regard (Church, 1984). According to Little (1982), a critical test to identify a nutrient as being deficient, is a positive reaction upon specific mineral supplementation. Ternouth (1997) stated that the determination of a P deficiency needs to address the dietary status of the animal, whether that is affecting production and whether the reserves of the animal have been reduced.

All of these factors clearly necessitated the development of more appropriate diagnostic aids or techniques. Read *et al.* (1986c) described the various criteria that has been used as diagnostic aids in assessing the P status of grazing ruminants. They also pointed out the shortcomings of using feed samples, especially hand-cut samples, for diagnosing a P deficiency and determining the P status of grazing ruminants with their selective grazing behaviour. This may be overcome by using oesophageal fistulated ruminants to sample the pasture for determination of dietary P levels. As a prerequisite, the salivary P must be labelled with ^{32}P (Little *et al.*, 1977) to account for salivary P contamination of the pasture samples.

Rib bone samples have proved to be a positive and reliable indicator of the P status of ruminants (Little, 1972; Groenewald, 1986; Read *et al.*, 1986c), because of bone's labile character of depositing and releasing minerals, depending on the physiological and nutritional status of the animal. Bone also has a stabile character and will not vary much in its composition as a result of feeding time, exercise, excitement or any kind of stress (Read *et al.*, 1986d), which is the case when blood samples are used. However, rib bone sampling still requires surgery, which may make it unattractive as a technique in many trials.

Blood samples are more readily obtainable and, therefore, have formed the basis of many diagnostic tests (Cohen, 1975). Read *et al.* (1986d) summarised the limitations of using blood samples as the indicator of mineral status reserves in animals. They concluded that low plasma P_i levels reflect low P intake and values of below 2 mg P/ml plasma was indicative of a P deficiency, but that plasma is unsatisfactory for distinguishing between higher intake levels. A normal blood P cannot be regarded as an index of adequate bone concentrations, because blood P levels can be maintained by resorption from the bones. The blood of mammalians is considered to be the medium of transport and the skeleton of reserve of *inter alia* minerals. Therefore, a combination of blood and rib bone analyses may provide a clear and reliable reflection of the P status of grazing ruminants.

Read *et al.* (1986c) showed that the ratio of Ca:P in bone does not differ much from the theoretically accepted ratio of 2:1. This is ascribed to the composition of the bone crystal: $Ca_{10}(PO_4)_6OH_2$ (Ganong, 1977, as cited by Read *et al.*, 1986c) and considering that there is no hormone (known to the authors cited) which function it is to bring about the differential resorption of P alone, but rather because of their interrelationship. The homeostasis of calcium (Ca) and P is regulated by calcitonin and the parathormone in response to circulating levels of ionised serum Ca^{++} (Underwood, 1981; Read *et al.*, 1986c). This is probably justified by the conclusion of Belonje and Van der Berg (1983) that the use of bone P analyses to assess P intake should, therefore, be viewed with caution, which may be the case on low Ca diets.

Mineral supplementation in general and P supplementation in particular is a complex aspect of ruminant nutrition. The response or reaction to supplementary feeding varies widely between areas. Differences in rainfall, temperature, vegetation and type of soil may have confounding effects on the results. Although many of the world's soils are low in phosphorus and support pastures which are of low P content (Cohen, 1975), the common belief among livestock producers throughout South Africa is that a P deficiency prevails. Underwood (1966) also stated "...there is no doubt that phosphorus deficiency is the most widespread and economically important of all the mineral disabilities affecting grazing livestock". According to De Waal *et al.* (1996) results of a trial that attempted to quantify the supplementary P requirement of beef cows at Armoedsvlakte, showed that animal production can still be satisfactory with more judicious but lower levels of P supplementation. Furthermore, efforts to justify supplementation of P with a resulting lowering of the cost of supplementation would be welcomed by beef cattle farmers.

With reference to the diverse results obtained with P supplementation on renowned research stations in the erstwhile Free State Region, there is a general uncertainty about the advantage of P supplementation on animal production in the Molopo region of the North-West Province. In a survey conducted during the early 1990's (1994, J.M. Van den Heever, personal communication), it was found that only 17% of the farmers in the Molopo region supplemented at the present departmental norm of < 10 g P/cow/day and < 80 g salt/cow/day. Most of the farmers supplemented far in excess of these guidelines and it were estimated by Van den Heever that a total saving of R3.5 million could be accomplished annually by sound supplementation practices. These factors gave rise to an urgent need to extend the renewed thrust in the research of P supplementation to beef cattle in the Molopo region of the North-West Province, similar to those studies that have been carried out on the *Tarchonantus*-veld of Armoedsvlakte (Read, 1986a,b,c,d) and Koopmansfontein (Spangenberg, 1997) and the *Tarchonantus*-thornveld of Vaalharts (Spangenberg, 1997).

In this study the objective was to determine whether a P deficiency exists on the veld of a site (namely Saratoga) in the Molopo region near Bray in the North-West Province. The study focused on the following aspects:

- the topographical, climatic and nutritional factors which may have an influence on the outcome of the research;
- the lick intake and the effects of supplementary P on the production of beef cows, because the animal's performance in terms of body mass changes can help in determining the P status of grazing ruminants;
- the effect of P supplementation on the reproductive performance of the beef cow and calf performance; and
- rib bone and blood samples as indicators of the P status of reproducing beef cows.

Chapter 2

Trial environment and procedures

2. Trial environment and procedures

South Africa experienced a major event in terms of its geo-political dispensation on 27 April 1994. To enhance the understanding of the context of this study, the terminology used in this dissertation is explained to avoid confusion with other studies or literature. In the past, prior to 27 April 1994, South Africa consisted of only four geo-political provinces, namely the Orange Free State, Transvaal, Natal and the Cape Province. Spangenberg (1997) mentioned that the National Department of Agriculture was structured and operated along seven designated agro-ecological divisions across the borders of these four provinces. The erstwhile Free State region, which was one of these seven agro-ecological regions (Spangenberg, 1997), is illustrated in Figure 2.1. After 27 April 1994 everything in South Africa, including the agricultural divisions, was structured according to the borders of the nine new provinces. Parts of the old Cape Province and the province of the Orange Free State used to be included in areas, which are now known as the Free State, the Northern Cape and the North-West Provinces. Therefore, references to Northern Cape (Saratoga) in the text of this dissertation will specifically refer to the present North-West Province.

2.1 Terrain, climate, vegetation and soil

Previously two other sites were included in the expansion of the renewed research program, namely Vaalharts and Koopmansfontein (Spangenberg, 1997). For this part of the renewed research on P supplementation to grazing beef cattle in the Molopo region of the North-West Province, one additional site was available; namely a private farm named Saratoga.

2.1.1 The farm, Saratoga

Saratoga, the farm of Mr. E.D. Graupner, is situated in the Molopo region of the North-West Province. This farm is approximately 270 km north-west of Vryburg, near Bray on

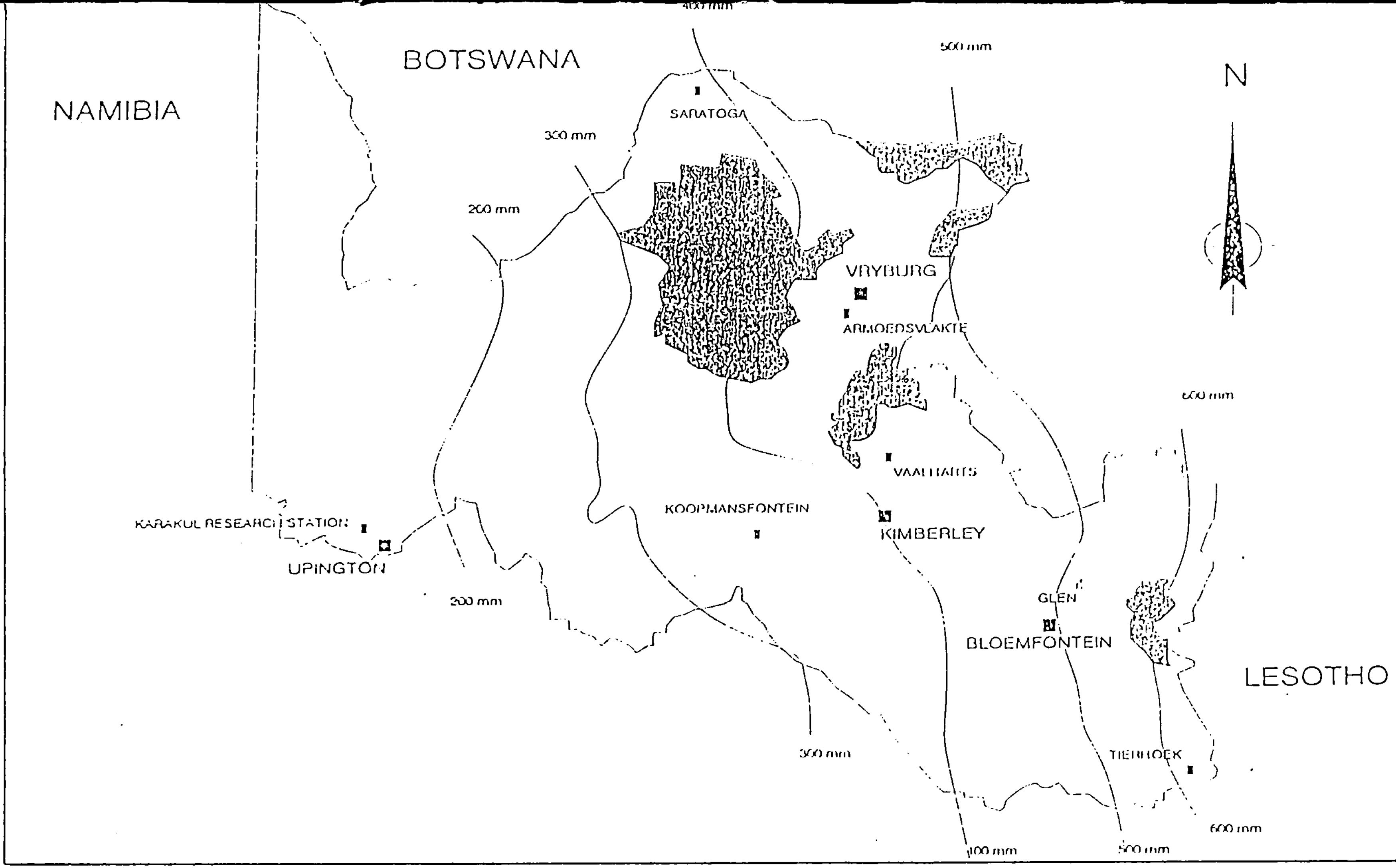

Figure 2.1 Map of the erstwhile Free State Region (prior to 27 April 1994) showing the rainfall isohyetes of the region

the Botswana border. This was an on-farm research trial, which is a very important element of the farming systems research (FSR) approach (1998, H.O. de Waal, personal communication). A similar on-farm trial was previously conducted with great success on the farm Tierhoek of Mr. C. van Rooyen in the Rouxville district in the south-eastern Free State (H.O. de Waal; H.P. Spangenberg, C. van Rooyen & J.M. Smith, 1991, unpublished data). Saratoga is at an altitude of 1 025 m above sea level and at 23°17' east longitude and 25°22' south latitude (Figure 2.1).

Pomfret is the nearest point to Saratoga with long-term meteorological data and is about 50 km south-southeast from Saratoga at 1 100 m above sea level and at 23°32' east longitude and 25°50' south altitude. Pomfret is situated in the summer rainfall area of South Africa, with a long-term average rainfall (1948-1984; National Meteorological Data Bank, ISCW, 1984) of 367.8 mm (see later Table 3.1). Ninety one percent of the rain occurs during late spring and summer from October to April in the form of thunderstorms. Hot summers and cold winters with regular frost further characterize the climate. Temperatures vary between -9°C and 42°C (Low & Rebelo, 1996).

Acocks (1988) classified the veld type as Kalahari Thornveld (no. 16a 4), with the subdivision Kalahari Thornveld Proper and a further subdivision *Western Form* of the Kalahari Thornveld; this, the typical form, is an extremely open savannah of *Acacia erioloba* and *A. haematoxylon*. The grass cover depends on the amount of rainfall during the growing season (Low & Rebelo, 1996). The grasses are tufted and entirely of the "white" type, mostly *Aristida* spp. and *Eragrostis* spp., with the silvery *Stipagrotis uniplumis,* which comprise the dominant grasses (Accocks, 1988). The soil consists of deep sandy to loamy sands of aeolian origin, underlaid by calcrete. Low and Rebelo (1996) concluded that the key to the environmental parameters is that the low rainfall on sandy plains and grazing by livestock influence the structure of this vegetation type.

It should be noted that the Molopo region of the North-West Province, *i.e.* the northern part of South Africa at this part of the border with Botswana, is only separated by the dry river bed of the Molopo River from Botswana. The veld immediately north of the border in southern Botswana is therefore similar to the trial site at Saratoga. Results from this study may therefore be extrapolated beyond the Molopo region in South Africa to a wide farming strip in southern Botswana.

2.2 Trial period

The trial with beef cattle began at the site (Saratoga) on 21 April 1992 and continued until the third set of calves were weaned in June 1994. It followed the same basic experimental design as in the trials at Vaalharts and Koopmansfontein as reported by Spangenberg (1997) (1998, De Waal, personal communication). Although, this trial was carried out over three years, this dissertation reports only on the first period of less than one year, *i.e.* from 21 April 1992 to 5 January 1993. This happened because the entire trial (both +P and –P) was replaced with other animals on 5 January 1993.

2.3 Veld (pasture)

2.3.1 Veld condition

The condition of the veld (pasture) was determined for each camp at the start of the trial towards the end of the growing season (April). Permanent line transects (250 points/transect/camp) were used to determine the botanical composition on the basis of the grass component, which is used as a standard reference for veld condition. A veld condition index (VCI) was determined for each camp as follows:

Classes		Factor		
Highly desirable	x	10	=	VCI
Desirable	x	7	=	VCI
Less desirable	x	4	=	VCI
Undesirable	x	1	=	VCI

The average VCI serves as a bench mark (BM) for the grazing capacity (GC) norm of 10 ha/Large Stock Unit (LSU; Meissner *et al.*, 1983; Fourie & Du Toit, 1983). Each camp's GC was determined by means of its VCI and the BM.

The bush component was analyzed on the same basis as the plant survey in each camp and is divided in three classes of bush-equivalents (BE) (Richter, 1991). The BE per hectare was determined as follows:

Classes		Factor						
<1 m	x	0.33	=	BE/transect	x	20[1]	=	BE/ha
1-2 m	x	1.00	=	BE/transect	x	20	=	BE/ha
>2 m	x	2.00	=	BE/transect	x	20	=	BE/ha

The sum of the three classes of BE/ha is the total BE/ha (Richter, 1991).

[1] A transect is 250 m x 2 m = 500 m^2 x 20 = 1 ha

2.3.2 Available above ground phytomass of the grass component

The available above ground phytomass of each camp was determined at the end of the growing season (April). In each camp 30 square (1 m^2) were cut on a specie group basis and the groups (highly desirable, desirable, less desirable and undesirable) determined per camp. The available dry matter of the grass component was also determined on a group basis per camp. This is also a standard reference for determining GC.

2.3.3 Sampling of the pasture

Six mature oesophageal fistulated (OF) oxen were used to collect samples of the veld for the determination of the *in vitro* digestibility of organic matter (OM) and nitrogen (N) content. Two groups of three OF oxen each were used at Saratoga to collect samples from the veld on three consecutive days at seasonal intervals, *i.e.* during the winter (July), spring (October), summer (February) and autumn (April). The collection of samples took place in both camps grazed by the cows at that particular time. Prior to the sampling periods the OF oxen were kept on veld in camps adjacent to the camps at the trial site for a week to serve as an adaptation period, before the actual collections of the samples commenced. However, the use of the OF oxen only began in August 1992, because of logistical reasons, and thus the samples were only collected twice (August and October) in the part of the trial under discussion (see 2.2)

The OF oxen were fasted overnight in order to minimize the possibility of regurgitation during sampling (De Waal *et al.,* 1989a). Drinking water was always available during the fasting periods. After being harnessed for the collection of pasture samples, the OF oxen were allowed to graze for about 30 minutes before being returned for the removal of the canvass collection bags with OF extrusa. The liquid fraction in the samples collected by the OF oxen were squeezed through four layers of cheesecloth, the liquid fraction discarded and the solid fraction dried at 50°C in a force draught oven (Engels *et al.,* 1981). After drying, the samples of each OF ox were pooled for the three days, ground in a Wiley mill to pass a 1 mm screen and stored in screw cap glass containers before being analyzed. The *in vitro* digestibility of organic matter (OMD) of the extrusa was determined according to the two-stage technique of Tilley and Terry (1963), as modified by Engels and Van der Merwe (1967). The OMD of the veld was then estimated according to the procedure described by Engels *et al.* (1981). The crude protein (CP) content of samples was determined as described by De Waal *et al.* (1989a).

During the same time hand-cut herbage samples were collected manually from the same camps where the OF oxen were used. Sheep hand shears was used to cut the herbage samples at a height of 5 cm in a set of 30 randomly selected plots (1 m^2 each). These samples were used for the determination of Ca, P and Mg content and to determine the available above ground phytomass. The *in vitro* OMD and the CP content of these samples were determined to compare them with the samples collected by the OF oxen.

2.4 Animals and treatments

The objective of the trial was to test the hypothesis whether a P deficiency exists at the site. Two treatments, namely a +P and a -P treatment, were applied where the animals in the +P treatment were the testers and the -P treatment the control. Sixty reproducing cows (beef cattle types) were used and all had calves at foot. Because of logistical difficulties, it is unfortunate that the trial could only start when the calves were already on average 126 days old. However, because of the long-term nature of this type of investigation it was deemed necessary to start the trial and not postpone it for another year. These lactating cows were chosen specifically to range in the age group of four to eight years of age, *i.e.* being able to bear their second, third, fourth, fifth or sixth calves. Both De Waal and Koekemoer (1997) and Spangenberg (1997) suggested that it is necessary to follow the long-term effects of P supplementation on the same individuals over a sustained period of at least three to four consecutive years.

The cows were allotted randomly within age groups to the two treatments (+P and -P). Each main treatment consisted of 30 animals as illustrated in Table 2.1. The respective treatments are referred to as designated in Table 2.1.

2.5 Supplementary feeding and grazing system

The cows in the +P and -P treatments were handled as two separate herds at a stocking rate of 10 ha/LSU. At the trial site, eight camps varying between 96 and 129 ha were used. Two adjacent camps were grazed at random in turn by cows in the +P and -P treatments, thus alternating between adjacent camps on a weekly basis to eliminate possible differences between camps and the available grazing. After two weeks, the two treatment groups were moved to a new set of camps. Although eight camps were used, the grazing of paired camps meant that a four-camp grazing system was effectively applied.

Table 2.1 The treatment design of the phosphorus (P) trail at Saratoga

Treatment	Description of the treatment	Numbers
+P	All year round access to a commercial phosphorus (P) lick, containing a minimum of 6.4 g P and sodium chloride (NaCl). The intake of the cows in this group was restricted to an average of 40 g dicalcium phosphate (DiCaP), which contained 6.4 g P. The lick consisted of 80 g salt (NaCl): 40 g DiCaP/cow/day.	30 lactating cows
-P	All year round access to a NaCl lick, which was restricted to 80 g/cow/day.	30 lactating cows

Supplementary P and salt were provided in the form of a commercial P lick to the +P treatment group. The -P treatment group received only a salt (NaCl) lick (Table 2.1).

Both supplements were provided at specified levels of intake to the respective treatment groups on a weekly basis in open lick troughs. Because of an increasingly excessive lick intake by the cows in both treatments, but especially in the -P treatment, this regime was changed from 22 October 1992 to a procedure where the licks were provided twice a week. The consumption of supplements was determined fortnightly when the two treatment groups were moved to a new set of camps.

2.6 The determination of the effect of phosphorus supplementation

2.6.1 Body mass

Initially the aim was to weigh the cows and calves at regular eight-weekly intervals, but due to practical and logistical circumstances beyond control, they were weighed at irregular intervals. Feed and water were not withheld prior to weighing in the morning, mainly to prevent disturbing the inherent grazing behaviour of the cows. However, the animals were weighed in the morning at a specific time. The calves were weighed at the same irregular intervals, together with the cows. Weaning of the calves took place in two batches at about seven months of age (see later 4.3).

2.6.2 Mating season and the calculation of reproductive performance

The 60 cows used in this study all had calves at foot at the start of the trial on 1 April 1992 and were chosen from the normal breeding herd on the farm. This calf crop at foot was produced according to the recommended period for mating of beef cows annually from 15 December until 28 February, which is commonly advocated in the erstwhile

Northern Cape (De Waal, 1990). However, during the 1991/92 mating season an adjustment was made considering Saratoga's different rainfall patterns (H.P. Spangenberg, 1997; E.D. Graupner, 1992; personal communications) and the cows were mated for a 60-day period from 15 February 1992 until 15 April 1992. Thus the mating period started 60 days later and the bulls were removed 45 days later than commonly recommended in this region (De Waal, 1990). The cows in each treatment (+P and -P) were mated with one bull. The two bulls rotated between the treatment groups, corresponding with the changeover of camps for cows within treatments, to compensate for any possible "bull-effects".

2.6.3 Sampling and analyses of rib bone and blood

Rib bone and blood samples were collected during peak lactation (April), during the period when the calves were weaned (July) and during the last third of gestation (October). Rib bone and blood samples were collected each time from the same initial randomly selected sample of 10 cows per treatment as suggested by De Waal and Koekemoer (1997).

2.6.3.1 Rib bone

The rib bone samples were taken according to the biopsy technique described by Little (1972), with an important modification as described by Read (1984) and used since in several local studies (De Waal & Koekemoer, 1997; Spangenberg, 1997). In the modified technique, full core samples of rib bone were taken instead of a single layer of cortical bone as described in the original bone biopsy technique. Samples were taken from the same rib (10th or 11th or 12th) on the same side of the animals at a specific sampling period. This ensured that the rib bone samples were comparable for that sampling period, but not necessarily between different periods because the degree of mineralization of one rib bone may differ from that of another one (Little & Minson, 1977; Read *et al.*, 1986c). The bone samples were analyzed for P, Ca and magnesium (Mg) concentrations and specific gravity (SG) according to the procedures described by De Waal (1979).

2.6.3.2 Blood

Blood samples were taken by jugular puncture with Venoject needles and Vac U Test tubes (green stopper), and then gently mixed with three drops of heparin to prevent any clotting of the blood (Read, 1984). The samples were kept cold on ice and spun down within 3 h of sampling and the plasma analyzed for inorganic phosphorus (P_i), Ca and Mg concentration, according to the procedures described by De Waal (1979). De Waal (1979) and Read *et al.* (1986d) cautioned that prior to and during sampling of the blood, every possible precaution must be taken to avoid those factors or situations which are known to have an influence on blood analysis of minerals.

2.6.4 Statistical analyses

A fully randomized design was used. Correlation analysis, one-way ANOVA and multiple comparisons (using Tukey's test) were performed on the data using SAS. The guidelines from the SAS Procedures Guide (1988) were followed and the second edition of SAS System for Regression (1991).

One-way ANOVA's were performed on the body mass of cows to test for differences between main treatments (+P vs. -P) at the specific dates of weighing for the year or reproduction season.

Calf performance (birth mass, 100-days mass and 205-days mass) was analyzed by performing one-way ANOVA's to test for differences between main treatments (+P and -P) for the year or reproductive season.

The data on rib bone and blood samples (peak lactation, weaning and late weaning) was analyzed by performing one-way ANOVA's to test for significant differences between main treatments (+P and -P) for the year.

Chapter 3

Rainfall, grazing aspects and lick intake

3. Rainfall, grazing aspects and lick intake

3.1 Results and discussion

3.1.1 Rainfall

The rainfall decreases progressively from east to west across the subcontinent and thus also across erstwhile Free State Region (De Waal, 1994b). At a given site rainfall varies between years and the incidence of years with below average rainfall exceed those with higher than average rainfall. In this region a given site is due to receive below average rainfall for about 55-60% of the years (De Waal, 1998; personal communication). Furthermore, the consistency in distribution during the rainy season is of greater importance than the absolute annual rainfall and thus is a factor greatly influencing seasonal droughts and consequently quality and quantity of veld (De Waal, 1990; 1994b).

The monthly rainfall from January 1992 to December 1992, the long-term average monthly rainfall of Pomfret (1948-1984) and the deviations from the averages are illustrated in Table 3.1. According to the long-term average, 91% of the annual rainfall is received during October to April. In the case of the present study the first rains only occurred in October 1992, followed by good rains in November 1992. The deviation of 224.3 mm below the long-term average, together with the extremely poor distribution of rainfall, is an indication of a very dry period during the trial year of 1992. No rainfall was recorded from January to September 1992 and, therefore, from an animal production point of view very harsh conditions prevailed during the trial period.

3.1.2 Grazing aspects

3.1.2.1 Botanical composition of the grass component

The botanical composition on the basis of desirability classes of the grass component is

TABLE 3.1 The monthly rainfall from January 1992 to December 1992, the long-term average monthly rainfall of Pomfret[1] (1948-1984) and the deviations from the averages

Year	**Month**	**Rainfall**			**Long-term Average (1948-1984)**	**Deviation from the average**
		Eastern camps[2] mm	**Western camps mm**	**Average[4] mm**	**mm**	**mm**
1992	Jan	0.0	0.0	0.0	62.5	-62.5
	Feb	0.0	0.0	0.0	54.1	-54.1
	Mar	0.0	0.0	0.0	67.9	-67.9
	Apr	0.0	0.0	0.0	37.3	-37.3
	May	0.0	0.0	0.0	13.6	-13.6
	Jun	0.0	0.0	0.0	7.6	-7.6
	Jul	0.0	0.0	0.0	4.6	-4.6
	Aug	0.0	0.0	0.0	2.1	-2.1
	Sept	0.0	0.0	0.0	5.6	-5.6
	Oct	8.0	8.0	8.0	21.5	-13.5
	Nov	113.0	107.0	110.0	44.6	+65.4
	Dec	15.0	26.0	20.5	41.1	-20.9
Total		136.0	141.0	138.5	362.8	-224.3

[1] = Pomfret, about 50 km south-southwest from Saratoga, is the nearest point to Saratoga with meteorological data.
[2] = Rainfall noted in the middle of the four eastern (E) camps.
[3] = Rainfall noted in the middle of the four western (W) camps. The distance between these two points is about 1 km.
[4] = Average rainfall of these two points (E and W).

illustrated in Table 3.2. The calculation of VCI, BM and the GC are presented in paragraph 2.3.1.

The highly desirable and desirable species comprised 81% of the total grass component (Table 3.2). This composition can be regarded as excellent (C.G.F. Richter, 1998; personal communication). In terms of the GC there are camps that were better or worse than the general norm of 10 ha/LSU which applies to the area. It is important to note that variation between the camps are not of great importance, because of the rotational grazing system that were applied (see 2.3.1). A general GC of 10 ha/LSU has been used throughout the trail for all the camps.

3.1.2.2 Bush density

The bush density is presented in Table 3.3 in terms of bush-equivalents per hectare (BE/ha).

According to Table 3.3, the average bush density of all the camps was 839.4 BE/ha, which is within bounds with similar studies by Richter (1991). It is also interesting to note that the negative effect of bush density on VCI (see Table 3.2), or the available above ground phytomass production (see later Table 3.4), is not clearly shown between the camps (see camps 3 and 5). It is ascribed to the fact that 75% of the bush component consists of the more desirable species, *Grewia flava*, *Boscia albitrunca* and *Acacia erioloba*. This composition is a direct result of deforestation. In this part of the Molopo region, it is common practice to eradicate the encroaching component of bush, *i.e. Acacia Mellifera* s.sp. *detinens* and *A. tortilis*, in an effort to reduce its negative effect on grazing capacity. This can be done chemically or by stem burning. At Saratoga the latter method was actively applied as a routine management practice (E.D. Graupner, 1997; personal communication). Further effects of deforestation are also reflected in the available above ground phytomass production (see later Table 3.4 and paragraph 3.1.2.3).

TABLE 3.2 Botanical composition on the basis of desirability classes of the grass component as determined with permanent line transects for all the camps at the end of the growing season (22-04-92)

Camps	Highly desirable species %	Desirable species %	Less desirable species %	Undesirable species %	Veld Condition Index (VCI)	Grazing Capacity (GC) (ha/LSU)
1	18.2	79.3	0.1	2.1	740.9	9.0
2	28.2	56.0	3.9	12.0	701.3	9.5
3	26.0	54.1	10.8	9.1	690.8	9.7
4	9.9	73.6	6.6	9.9	650.4	10.3
5	13.4	73.6	7.5	5.4	684.9	9.8
6	8.2	46.6	31.5	13.8	547.4	12.2
7	18.7	56.1	15.7	9.6	651.8	10.3
8	19.8	68.4	0.4	11.4	689.8	9.7
Average	17.8	63.5	9.6	9.2	669.7[1]	10.0

[1] = The average Veld Condition Index (VCI) serves as a Bench Mark (BM).

TABLE 3.3 The density of the bush component as determined with permanent line transects for all the camps at the end of the growing season (22-04-92)

Camps	Classes			Total BE/ha
	< 1 m BE/ha[1]	1-2 m BE/ha	> 2 m > BE/ha	
1	99.0	360.0	80.0	539.0
2	204.6	280.0	320.0	804.6
3	363.0	640.0	160.0	1163.0
4	244.2	160.0	200.0	604.2
5	283.8	200.0	880.0	1363.8
6	237.6	340.0	320.0	897.6
7	204.6	180.0	160.0	544.6
8	158.4	440.0	200.0	798.4
Average	224.4	325.0	290.0	839.4

[1] = Bush-equivalents per hectare (BE/ha).

3.1.2.3 Available above ground phytomass

The available above ground phytomass production is illustrated in Table 3.4 on a specie group basis as kg DM/ha.

The average available above ground phytomass production across all camps consisted of 80% highly desirable and desirable species. The average total production was also high (1635 kg DM/ha) across all camps, not withstanding the extremely dry year.

Six months later (23 October 1992) the available above ground phytomass production of camps 2 and 6 were determined again. The influence of the drought is reflected in the drastic decline in available DM since 24 April 1992, but it was calculated that there was still enough material to carry the animals for more than a year. The fact that camp 6 still had a covering of more than 1000 kg DM/ha, can be ascribed to the small percentage highly desirable and desirable species in this camp (see Table 3.2). It is clear that all the desirable species in camp 6 had been selected by 23-10-1992 (see Table 3.4). These effects are also reflected in the CP content of grazing material which was selected by the OF oxen (see later Table 3.5).

3.1.2.4 Quality of the grazing

The CP content and the DOM of plant material collected by the OF oxen are illustrated in Table 3.5.

Because of logistical difficulties the collection of the grazing samples with the OF oxen could only start from August 1992 at Saratoga. Low values, especially for CP but also for DOM had been expected because of the prevailing drought (see Table 3.1). Although the quality of the grazing is very important, the total daily intake of DM with a high digestibility remains of utmost importance in terms of animal production.

TABLE 3.4 The available above ground phytomass production (kg/ha) as determined with the cutting of quadrants on 24-04-92 and 23-10-92[1]

Date	Camps	Highly desirable kg/ha	Desirable kg/ha	Less desirable kg/ha	Undesirable kg/ha	Total kg/ha
24-04-92	1	278.7	1361.3	0.0	0.0	1640.0
	2	245.3	1027.3	179.3	8.7	1460.7
	3	140.0	1024.7	586.7	67.3	1818.6
	4	228.0	1155.3	128.7	109.3	1621.3
	5	216.0	1558.0	165.3	93.3	2032.7
	6	113.3	847.3	892.7	100.7	1954.0
	7	178.0	919.3	154.0	57.3	1308.7
	8	138.7	1065.3	0.0	40.0	1244.0
	Average	192.3	1119.8	263.3	59.6	1635.0
23-10-92[2]	2	44.0	407.3	0.0	22.0	473.3
	6	0.0	559.3	486.0	1045.3	1045.3
	Average	22.0	243.0	11.0	759.3	759.3

[1] = On the same date when the OF samples were collected, quadrants were cut manually for chemical analysis and determination of the available above ground phytomass.

Table 3.5 The crude protein (CP) and digestibility of organic material (DOM) of plant material collected by oesophageally fistulated (OF) oxen

Date	Camps	% CP[2]	% DOM
14-08-92	1	4.2	55.3
	5	4.4	58.0
Average		4.3	56.7
23-10-92	2	4.0	55.9
	6	3.7	59.3
Average		3.9	57.6

[1] = On the same date when the OF samples were collected, quadrants were cut manually for chemical analysis and determination of the available above ground phytomass.

[2] = Crude protein (CP) expressed on an OM basis (ash free).

Reasonable levels of animal production may be expected during months with poor quality grazing, provided that intake is not impaired, nor that nutrient requirements imposed by physiological status (growth, lactation) are too high (De Waal, 1990).

The inability of hand-cut samples to represent the diet selected by grazing ruminants, such as that selected under free ranging conditions on veld, is illustrated in Table 3.6. The CP content of the plant material selected by the OF oxen (Table 3.5) was about twice that of the samples collected manually from the veld (Table 3.6). It is probably safe to assume that the same applied for the P content of the two types of samples collected from the veld, *i.e.* manually or OF collected samples. The grazing samples are contaminated with P from the saliva when OF oxen are used to collect the samples. With advanced techniques it possible to mark the P in the saliva with radioactive ^{32}P. However, it was not applied in the present study.

The data in Tables 3.5 and 3.6 also show that the DOM did not vary to the same extent as CP between the two sampling methods, although it was consistently higher in the OF collected samples.

3.1.3 Intake of lick

The intake of phosphorus and/or salt by the cows in the +P and -P treatments is given in Table 3.7.

Table 3.7 shows that with the start of the study, both groups had a very high average daily voluntary salt intake. Note that although it is not shown in the data, this intake also means that the lick addition, which had been set out for a week in anticipation of an average daily intake of 80 g NaCl/cow/day, was devoured in just more than a day. At this stage there were respectively 2 and 15 cows of the +P and -P treatments, which showed symptoms of stiffness, anorexia and incoordination. These symptoms have also occurred in other studies (Spangenberg, 1997). In an effort to curb this strange phenomenon and decrease the lick intakes by the animals, the number of lick troughs were increased for

TABLE 3.6 The crude protein content (CP), digestibility of organic material (DOM), phosphorus (P), calcium (Ca) and magnesium (Mg) of plant material that was collected manually through the cutting of quadrants[1]

Date	Camps	% CP[2]	% DOM	% P	% Ca	% Mg
14-08-92	1 5	2.3 2.4	47.4 45.5	0.0 0.0	0.2 0.2	0.1 0.1
Average		2.3	46.5	0.0	0.2	0.1
23-10-92	2 6	2.2 2.2	52.5 53.8	0.0 0.0	0.1 0.1	0.2 0.2
Average		2.2	53.2	0.0	0.1	0.2

[1] = On the same date when the OF - samples were collected, quadrants were cut manually for chemical analysis and determination of the available above ground phytomass.
[2] = Crude protein expressed on a DM basis (ash free).

TABLE 3.7 The phosphorus and/or salt lick intake of the +P and -P cows (g/cow/day)[1]

Date	+P cows		-P cows
	P (g)	NaCl (g)	NaCl (g)
92-04-21	36	450	450
92-06-30	25	311	460
92-10-22	14	177	316
93-01-05	6	80	300

[1] = See text (paragragh 3.1.3) for explanation on the high values for lick intake.

both treatments. After weaning (30 June 1992) a decrease in lick intake of the +P cows occurred, while the lick intake of the –P cows still remained at a very high level. This was in agreement with the results at Koopmansfontein (Spangenberg, 1997). At this stage no obvious signs were left of symptoms in the +P treatment. In the –P group, however, 17 of the -P cows' still showed some signs of the above-mentioned symptoms. Based on experienced gained in a similar situation at Koopmansfontein, it was decided to present the weekly allowance of licks for both the treatments from 22 October 1992 in two smaller portions per week. One portion of the weekly allowance was given at the beginning (Monday) and the other one in the middle (Thursday) of the week. This procedure caused a further decrease in salt intake of cows in the +P treatment to an acceptable level of 80 g NaCl and 6 g P per cow per day (De Waal, 1994a). On the other hand, although there was a decrease in the salt intake of cows in the -P treatment, it was still maintained at a high level. Eventually two of the affected cows in the -P treatment died in December 1992.

The sudden decrease in body mass of the cows (see later 4.1), especially in the -P treatment just after the start of the study, could probably be attributed to the high salt intake. This hypothesis is in agreement with results obtained at Koopmansfontein (Spangenberg, 1997) and with sheep (young Merino wethers and lactating Merino ewes) at Glen (De Waal *et al.*, 1989a,b; H.O. de Waal, 1985; unpublished data). In these studies the performance of cattle and sheep, in terms of body mass changes, had been adversely affected by daily high levels of salt. The cattle at Koopmansfontein were caught in a cycle of high salt intake - high water intake - low intake of grazing material (De Waal, 1998; personal communication).

Based on results reported by De Waal *et al.* (1989a,b), it was deemed necessary to provide the –P groups in trials of this design with a NaCl lick in order to equalize any possible negative effects between groups (due to NaCl), especially since NaCl was used in the +P groups as a carrier for P supplementation (De Waal, 1994a). However, because of reasons not yet fully understood, late pregnant and/or cows in early lactation at Koopmansfontein started to consume excessive amounts of NaCl, both in the –P and +P groups (De Waal, 1994a; Spangenberg, 1997). According to De Waal (1994a) it was suspected that omission of less palatable dicalcium phoshate from the lick, played a major role in allowing excessive levels of NaCl intake by the –P group. In the case of the +P group, lick intake (and thus NaCl) was also high, but not as high as the –P group (De Waal, 1994a; Spangenberg, 1997). Clearly an excessive intake of NaCl has a negative effect on several important physiological systems (De Waal *et al.*, 1989a,b; De Waal, 1994a).

The animals that were affected by NaCl during the trial at Koopmansfontein eventually recovered in terms of body mass and reproduction, but only after a period of no less that three years (Spangenberg, 1997). Spangenberg (1997) also mentioned that one of these emaciated cows was put on a complete feedlot diet and did not recover, not even with injection of P substance. The post mortem that was done on this cow at Onderstepoort, revealed nothing. Therefore, based on the experience gained at Koopmansfontein it was decided to replace the entire trial (both +P and -P) with other animals on 5 January 1993. If this step was not taken, the affected animals could have taken too long to recover (similar to the experience at Koopmansfontein) and thus jeopardize the objectives of the trial at Saratoga.

In the absence of details provided by Read *et al.* (1986b) for their trail at Armoedsvlakte, De Waal *et al.* (1996) deduced (Table 8; Read *et al.*, 1986b) that the +P cows consumed on average about 59 g NaCl per day (*e.g.* 47, 74, 61, 62 and 52 g NaCl per day, respectively, for successive years), while the consumption of NaCl by the –P group is, however, unknown. This was substantially lower than the 110 g NaCl per day (*e.g.* 93, 104, 162, 151, 53, 87 and 102 g NaCl per day, respectively, for successive years, or parts of years) reported by De Waal *et al.* (1996) in their trial at Armoedsvlakte where P was supplemented at different levels and periods via rumen fistulae to the cows. In view of these values, the cows in this trial (Table 3.7) consumed voluntarily considerable higher levels of NaCl.

According to De Waal (1994a) it was observed at Saratoga that some of the –P group cows consumed about 500 g NaCl each in a matter of 10 minutes. Obviously, calculation of the average daily intake of individuals in the group and therefore tended to mask the true extent and cause of the problem (De Waal, 1994a).

Spangenberg (1997) mentioned that there are no clear guidelines for NaCl requirements under grazing conditions. According to the NRC (1984) a cow needs only a small amount of Na (0.08% of diet which is ±8 g/day) and Cl per day to meet her requirements. Thus, despite the common belief that there is little danger of misapplication because voluntary NaCl intake is regulated by satiety (Louw, 1979; Berger, 1992), high intake of NaCl is questionable and may cause moralities in cattle (Trueman & Clague, 1978).

Chapter 4

Animal production

4. Animal production

4.1 Body mass of the cows

The average body mass of the cows in the two treatments (+P and –P) as well as the difference between the two groups at each weighing session, is illustrated in Table 4.1. The body mass of the cows is also presented graphically in Figure 4.1.

As discussed (see 2.4), the trial commenced with cows and calves at foot. On 21 April 1992, the calves were on average 126 days old, varying from 60 to 155 days in the +P treatment group and from 54 to 171 days in the –P treatment group. Conversely, the number of days that the cows were in lactation, varied by the same margin. During the period when the cows were subjected to the +P and –P treatments they were on average between 126 and 196 days in lactation. This may have had an effect on the extent to which they were affected by the P supplementation.

At the start of the trial there was a difference of only 7 kg in body mass between the two groups of cows (+P and –P). This difference between the treatments increased significantly ($P < 0.05$) as the trial progressed (Table 4.1).

The loss in body mass up to 30 June 1992 is of interest. This decrease in body mass of mature, reproducing beef cows in the last third of lactation towards the end of the lactation period (Figure 4.1) may partly be accounted for by the effect of the severe drought experienced during this time. In circumstances where the general grazing conditions were not affected by drought, the expectation would have been for the cows to even increase in body mass during this phase of lactation approaching weaning of their calves (De Waal, 1990). As described later in paragraph 4.3, because of the drought the bulk of the calves in both treatments were weaned on 30 June 1992 and the youngest remainder on 13 August 1992. Also of importance, is the fact that the -P cows lost more than twice the body mass during this period (21 April 1992 to 30 June 1992), compared to the +P group (47 kg vs. 22 kg). The body mass loss of the +P and –P cows up to

TABLE 4.1 Average body mass of the cows in the two treatment groups (+P and -P)

Date	Phosphorus and salt (+P) Kg	Salt (-P) kg	Difference between +P and -P treatment kg
92-04-21[1]	455	448	7
92-06-30[2]	433	401	32*
92-07-23	438	389	45*
92-08-13[3]	460	401	59*
92-10-23[4]	446	387	59*
93-01-05	494	390	104*
Average	454	403	51

1 = Peak lactation.
2 = Weaning (first group of calves).
3 = Weaning (late group of calves).
4 = Last third of pregnancy.
* = Average differs significantly ($P \leq 0.05$).

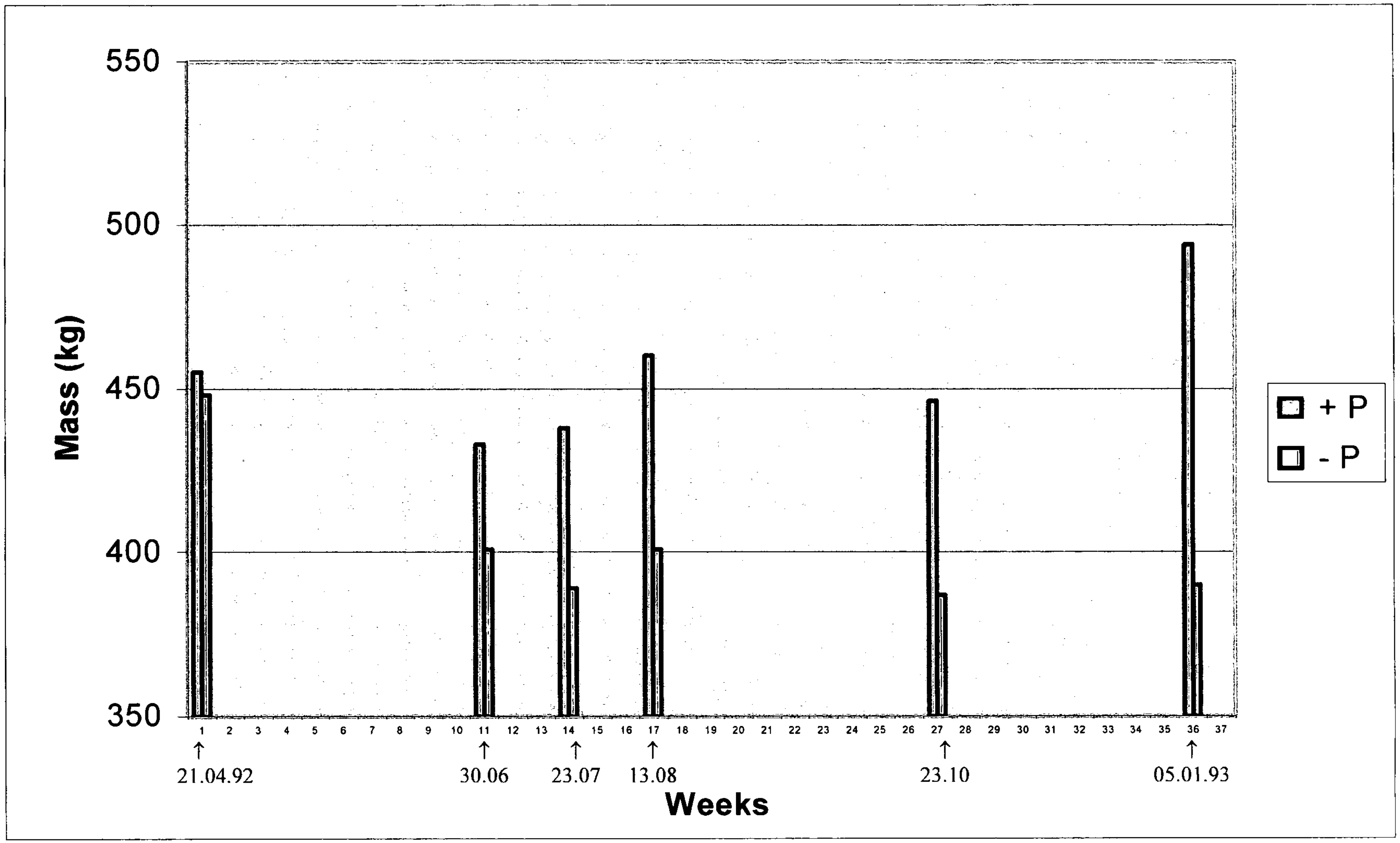

Figure 4.1 The average body mass of the cows that received salt and phosphorus (+P) or only salt (-P)

30 June 1992, as a % of the body mass at the start of the trial, relative to the age of their calves at the start of the trail (or days in lactation for cows), are shown in Figures 4.2 and 4.3. At the first glance it is obvious that apart from the greater average body mass loss of the -P cows (47 kg vs. 22 kg), the general pattern of body mass loss between the two treatment groups also differed. In the –P treatment, cows with older calves tended to loose more body mass. In the +P treatment, cows seem not to have been affected in this way. No plausible explanation can be given for this obvious difference between the two treatment group.

Although the –P group alternately gained and lost mass (Figure 4.1), they more or less maintained a constant body mass from 30 June 1992 until the entire group of cows in this part of the trail was replaced on 5 January 1993. The gap in body mass between the +P and –P cows widened from the start of the trial (21 April 1992) until the end (5 January 1993). This could be indicative of a P deficiency that developed in the –P treatment as the trial progressed (Spangenberg, 1997). It must be kept in mind that this gap developed from the start of the trial (21 April 1992), at the same time when drought conditions started at Saratoga. It is suspected that this may have had a major influence on the body mass of the cows. Furthermore, it seemed as if the +P and -P cows were able to recover in terms of body mass after the first rains occurred in October 1992 (see 3.1.1) with the concomitant positive response in veld quality.

The decrease in body mass seen at the weighing on 23 October 1992, relative to the previous weighing on 13 August 1992, can be attributed to the serious drought experienced. Despite the fact that ample DM was apparently available (see Table 3.4) and the CP content and DOM of the selected diet did not change much from August to October 1992 (see Table 3.5), it seems as if though the animals found it difficult to obtain sufficient quantities of nutrients because most of the high quality material had already been consumed. Thus, voluntary feed intake was depressed. Under normal circumstances temporary changes in quality are not considered to be a serious problem, provided animal production is synchronized with the seasonal changes or limitations of nature which are

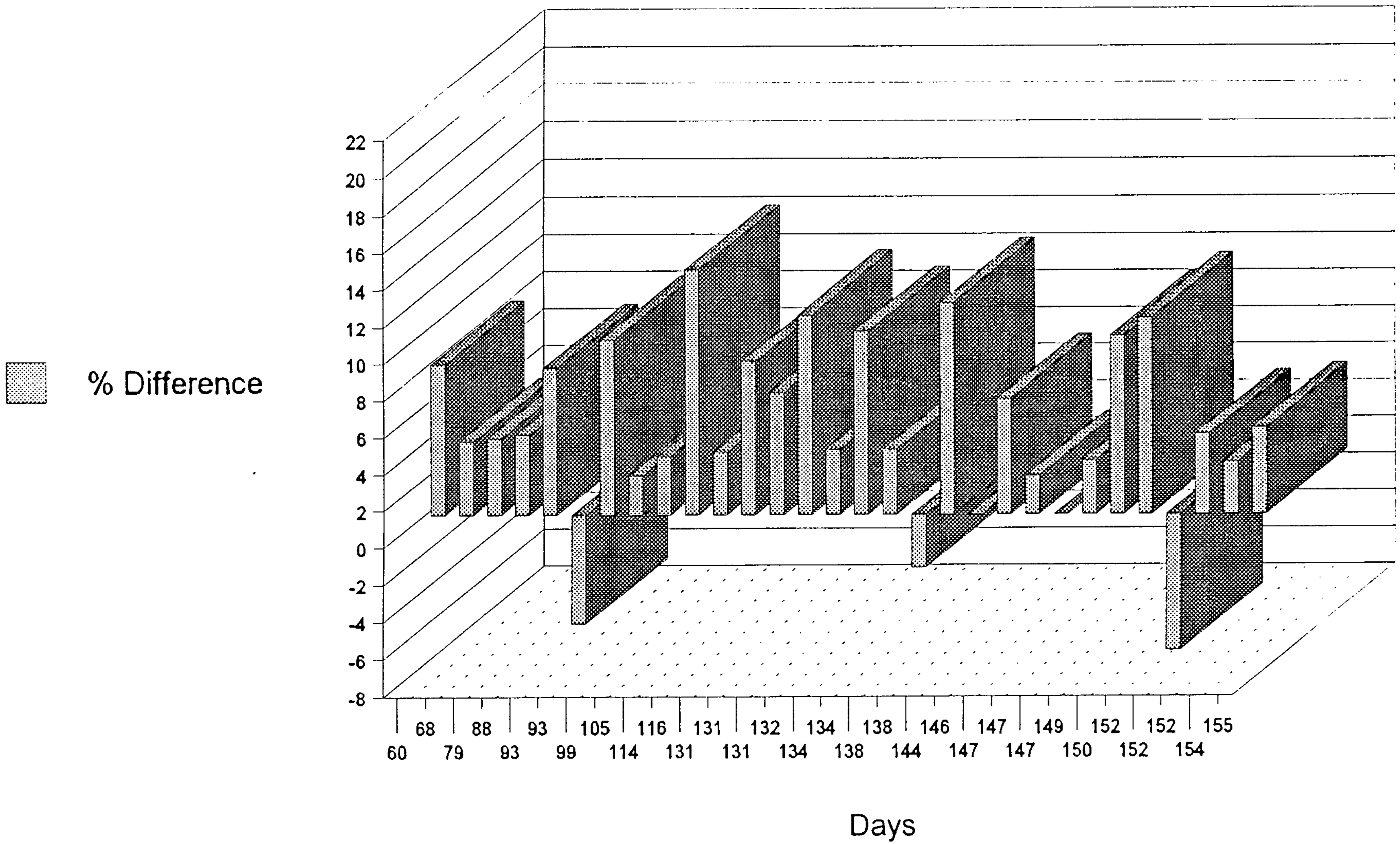

Figure 4.2 The body mass loss (%) of +P treatment cows at Saratoga, relative to the age of their calves at the start of the trail (or days in lactation for cows)

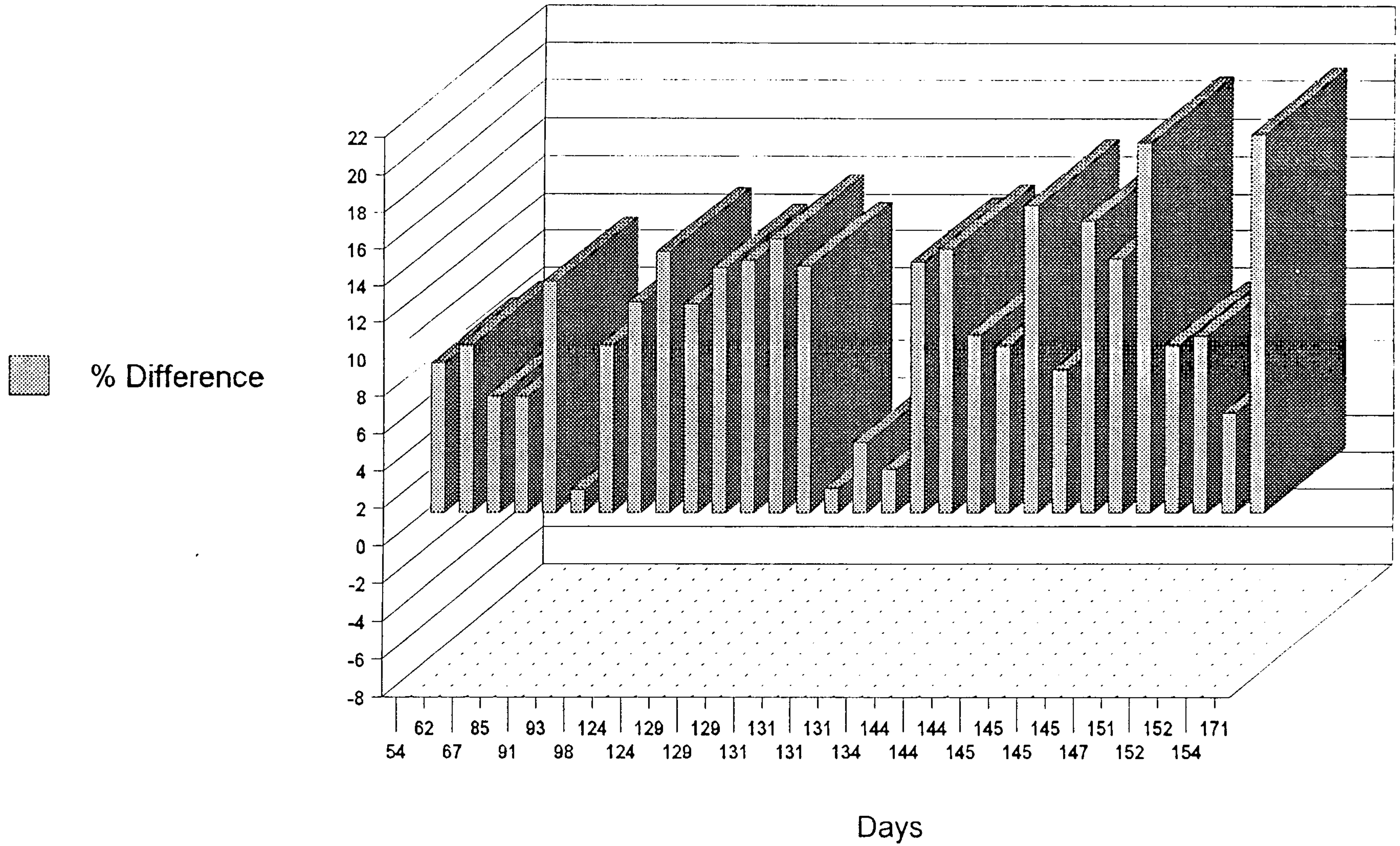

Figure 4.3 The body mass loss (%) of -P treatment cows at Saratoga, relative to the age of their calves at the start of the trail (or days in lactation for cows)

reflected in rainfall and quantity and quality of the veld. Changes in body mass of grazing ruminants also reflect this seasonal flux of veld and a loss of about 12–15% in body mass by reproducing cows may still be regarded as within normal bounds (De Waal, 1990). De Waal (1990) showed that the body mass of cows changes through the year as a result of successive physiological stages (gestation and lactation).

The –P cows showed some recovery in terms of body mass at the end of the trial, despite being withheld from supplementary P. A close observation in this trial and two other similar trials at Koopmansfontein (Spangenberg, 1997), and observations in following years in the trial at Saratoga (Spangenberg *et al.*, 1993; Spangenberg *et al.*, 1995), showed that the dominant cows in the herds (larger ones) consumed large amounts of salt, eating themselves to a standstill, followed in this routine by the less dominant cows once the dominant cows have eliminated themselves.

According to De Waal (1994a) and Spangenberg (1997) the sudden loss of body mass and emaciation in especially the –P cows at Koopmansfontein might be ascribed to the high initial intake of salt, which could also be the case in this trial. This hypothesis is based on the results obtained in a study with Merino wethers at Glen (De Waal *et al.*, 1989a), where the performance of grazing wethers was seriously affected by high NaCl levels, especially in terms of body mass changes and wool production. In this scenario an animal may get trapped in a cycle of a high NaCl intake, causing a high water intake with a corresponding lower intake of herbage. The results which were obtained in the trial at Koopmansfontein (Spangenberg, 1997) strengthened this hypothesis. In the latter trial the cows deteriorated and collapsed in order of dominance, because they dominated at the lick troughs until the continuous high salt intake caused serious symptoms of emaciation. During the trial, at Koopmansfontein (Spangenberg, 1997) it was also observed that individual cows gorged large quantities of salt in a short period of time. According to De Waal (1994a) it was observed that some of the dominant cows in the –P group at Saratoga consumed about 500 g NaCl each in a matter of 10 minutes.

According to Spangenberg (1997), an immediate and natural reaction would have been to label the –P treatment group at Koopmansfontein as being P deficient, but then it has to be for the right reasons. The poor performance of the –P cows at Saratoga could not, without reasonable doubt, be ascribed primarily to a lack of P in their diet, but rather the compounding affects of a sudden overindulgence in NaCl with its negative effects, *inter alia* possibly an induced P deficiency. This requires urgent investigation.

4.2 Reproductive performance

According to Spangenberg (1997) the ability of the cows in different treatment groups to produce a calf, dead or alive (calving percentage), as well as their ability to rear the calves to weaning (weaning percentage), were important indicators of response to P supplementation. In this trial at Saratoga, it was the objective to measure the effects of P supplementation on reproductive performance of the cows. However, as indicated elsewhere (2.4 and 4.1) this trial started with cows with calves at foot. Therefore, very little can be said in this first phase of the trial on reproduction, except that it started with 30 cows with calves at foot in each of the +P and –P treatments (see 2.4) and that all 30 calves in both the +P and –P treatment groups were weaned successfully.

4.3 Body mass of calves

It is not standard practice to record birth mass in the commercial beef cattle herd at Saratoga. Therefore, a standard birth weight was assumed for the calves in this trial.

The standard assumed birth mass, average 100-day corrected body mass, average corrected 205-day body mass and the average daily gains of calves in the different treatments are presented in Table 4.2.

This trial started when the calves were on average 126 days old (see 4.1) and continued until weaning. Therefore, the different treatments could only affect the later stages of lactation of the cows and thus the growth of their calves. The performance of the calves

TABLE 4.2 The average 100-day and 205-day corrected body mass and the average daily gain (ADG) of calves in the +P and -P treatments

Variable	Birth[1] mass Kg	n	100-day mass kg	ADG (Birth - 100 days) kg/day	205-day mass kg	ADG (100 days – 205-days) kg/day	ADG (Birth – 205 days) kg/day
+P treatment							
Heifers	35	15	128	0.9	208	0.7	0.9
Bulls	35	15	134	1.0	214	0.7	0.9
Average (+P)	35		131	1.0	211	0.7	0.9
-P treatment							
Heifers	35	16	126	0.9	203	0.6	0.8
Bulls	35	14	133	1.0	213	0.7	0.9
Average (-P)	35		129	0.9	208	0.6	0.8

* = Averages differ significantly ($P \leq 0.05$).
[1] = Calves not weighed at birth - average birth mass assumed.
n Number.

in terms of a 100-day corrected mass, *i.e.* before the trial started when they were on average 126 days old, is also presented in Table 4.2 to provide greater perspective on their overall performance.

Throughout this entire first phase of the trial in 1992, there was a non-significant ($P < 0.05$) difference in terms of body mass and ADG between the two treatments. Differences that may have occurred could not be ascribed only to the effect of the treatment. Results from a later study with reproducing cows at Armoedsvlakte (De Waal *et al.*, 1996) also showed no significant difference in weaning mass between treatments which suggested that in times of nutrient deficiencies the cow sacrifices herself to shield the calf from such deficiencies, ensuring the existence of the species. Differences in average weaning mass also reflect individual genetic variation in milk yield and growth potential, as well as differences in weaning mass between bulls and heifers (De Waal *et al.*, 1996). As was to be expected, the bull calves tended to have a higher growth rate than the heifers as reflected in the 100-day and 205-day body mass (Table 4.2). However, in the trials at Vaalharts and Koopmansfontein (Spangenberg, 1997) significant differences ($P < 0.05$) occurred for 205-day body mass and the ADG. De Waal *et al.* (1996) stated that the tendency for cows receiving the lowest levels of P supplementation to wean lighter calves suggests that there is a limit to which body reserves of the dam can be utilized before having an effect on milk yield and the calf. Read *et al.* (1986b) reported a 27% difference (231.8 kg vs. 181.8 kg) in the average 210-day weaning mass of calves from supplemented and unsupplemented dams at Armoedsvlakte.

It is important to note that the oldest calves were weaned about a month earlier than the normal weaning date (July-August), *i.e.* on 30 June 1992, and those calves remaining that were too young and small were weaned later on 13 August 1992 (see Table 4.1). The reason for this was to relieve further possible stress on the cows in view of the serious body mass losses and other symptoms (stiffness, anorexia and incordination) that have been noted at that stage.

In summary, it seems as if the effects of supplementation on the cows were not passed on to their calves. In retrospect, this is not surprising, given the average age of 126 days for the calves when the trial commenced. However, as stated previously (see 2.4) despite the logistical difficulties encountered which prevented the trial from starting earlier, it was deemed necessary to start the trial in April of 1992 and not postpone it for another year. Valuable information was gathered in this first phase of the trial, which ensured the implementation of further corrective procedures in the following years (De Waal, 1998; personal communication).

Chapter 5

Rib bone and blood as indicators of phosphorus status

5. Rib bone and blood as indicators of phosphorus status

5.1 Results and discussion

5.1.1 Rib bone

The SG and mineral content of fresh rib bone sampled at specific production stages (late lactation, weaning and late pregnancy) from cows in the different treatments at Saratoga, are illustrated in Table 5.1.

Little (1972), Little and McMeniman (1973), De Waal (1979) and Read *et al.* (1986a,c) concluded that mineral concentrations are more sensitive when expressed per unit volume (mg/cm^3) of fresh bone than as a percentage (mg/mg) of dry bone. Therefore, bone mineral concentrations are expressed as mg/cm^3 fresh bone. Biopsies were performed on the same rib of the same side of the animals at a specific sampling occasion (Read *et al.*, 1986c). In this regard, Little and Minson (1977) mentioned that this procedure makes comparisons between treatments valid for a specific sampling occasion, but not necessarily between different sampling occasions because the degree of mineralization of one rib may differ from that of another.

Little and Shaw (1979) stated: "levels over 150 mg P/cm^3 in samples from the 12th rib would indicate adequacy and levels 'around' 120 mg P/cm^3, deficiency, although the nutritional history of the animals must also be considered before pronouncing them as being P deficient because it is possible for concentrations higher than 150 mg P/cm^3 to be observed in bone samples from P deficient animals". Levels of 146 mg P/cm^3 (Little, 1972) and 140 mg P/cm^3 (Little & Ratcliff, 1979) are regarded as normal, while a level of 118 mg P/cm^3 (Little, 1972) may be indicative of P deficiency. However, more recently and with the modified technique of sampling, Read (1984) and Groenewald (1986) reported levels of 144 mg P/cm^3 and 162 mg P/cm as being normal, while 124 mg P/cm^3 and 132 mg P/cm^3 may be indicative of a P deficiency. Spangenberg (1997) stated that interpretation of clinical and sub-clinical symptoms of P deficiency might also have an influence on these reported critical values (those levels above or below the values associated with specific clinical signs) and the variation of values, regarded as normal or deficient.

5.1.1.1 SG of rib bone

A loss of mineral matter increases bone's porosity and must, therefore, be reflected in a reduced SG (Spangenberg, 1997). This was also the case at Saratoga, where the SG differed significantly ($P \leq 0.05$) for +P vs. -P cows at weaning as indicated in Table 5.1 and Figure 5.1. This suggests that a significantly ($P \leq 0.05$) higher level of bone demineralization occurred in the -P treatment. Read *et al.* (1986c) concluded that SG may be less sensitive than P content expressed as mg P/cm^3 fresh bone when investigating a possible sub-clinical asphoshorosis. However, with more severe cases, both SG and P content of the fresh bone may be equally conclusive in identifying a P deficiency.

5.1.1.2 P content of rib bone

Significant ($P \leq 0.05$) differences in the P content of fresh bone (Table 5.1) occurred only once between the treatments, namely at weaning as presented in Figure 5.2.

Both treatments showed more or less the same P-reserves per cm^3 fresh bone during late lactation, but the -P treatment had mobilized much more P than the +P treatment towards weaning. If P levels 'around' 120 mg/cm^3 may be a general indication of a P deficiency, it seems that the -P treatment did develop a slight P deficiency, as shown at weaning. However, by the time bone was sampled during late pregnancy, the slight deficiency was not discernable, as reflected in the higher bone P values (Table 5.1). This is in agreement with the results of a similar study at Glen (Read *et al.*, 1986b; Read 1984).

The -P treatments, in both these studies (Glen and Saratoga), had low P-contents of the fresh bone (112.1 vs. 112.4 mg P/cm^3) at weaning (first reproduction year) and recovered

TABLE 5.1 Average specific gravity (SG), phosphorus (P), calcium (Ca) and magnesium (Mg) contents of rib bone samples taken at specific production stages

Variable	+P treatment				-P treatment			
	Late lactation[1]	Weaning[2]	Late pregnancy[3]	Average	Late lactation[1]	Weaning[2]	Late pregnancy[3]	Average
Number (n)	10	10	10	10	10	10	10	10
Specific gravity (SG)	1.5	1.6	1.5	1.6	1.5	1.5	1.5	1.5
mg P/cm^3	125.4	124.4*	141.9	130.6	124.3	112.1*	127.8	121.4
mg Ca/cm^3	286.7*	191.8	191.9	223.5	225.5*	178.9	176.9	193.8
mg Mg/cm^3	2.3*	13.6*	7.0	7.6	4.6	10.6*	6.2	7.1
Ca:P	2.3	1.5	1.3	1.7	1.8	1.6	1.4	1.6

1 = 1992-04-21
2 = 1992-06-30
3 = 1992-10-22
* = Averages between treatments in corresponding periods differ significantly ($P \leq 0.05$).

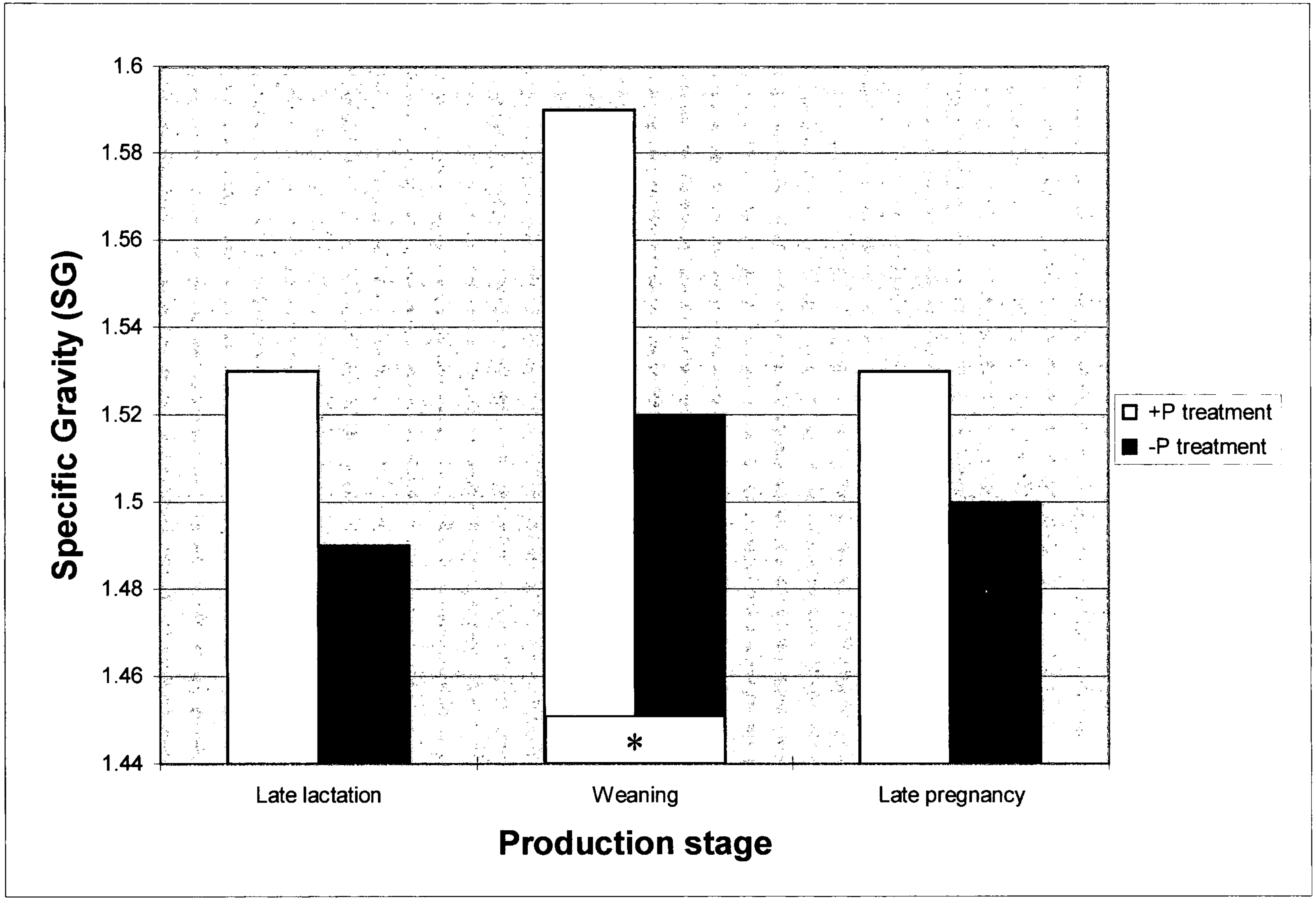

FIGURE 5.1 Average specific gravity (SG) of rib bone samples taken at specific production stages from the two treatments at Saratoga.
* Averages differ significantly ($P \leq 0.05$) for corresponding treatments (+P vs. -P) at each interval.

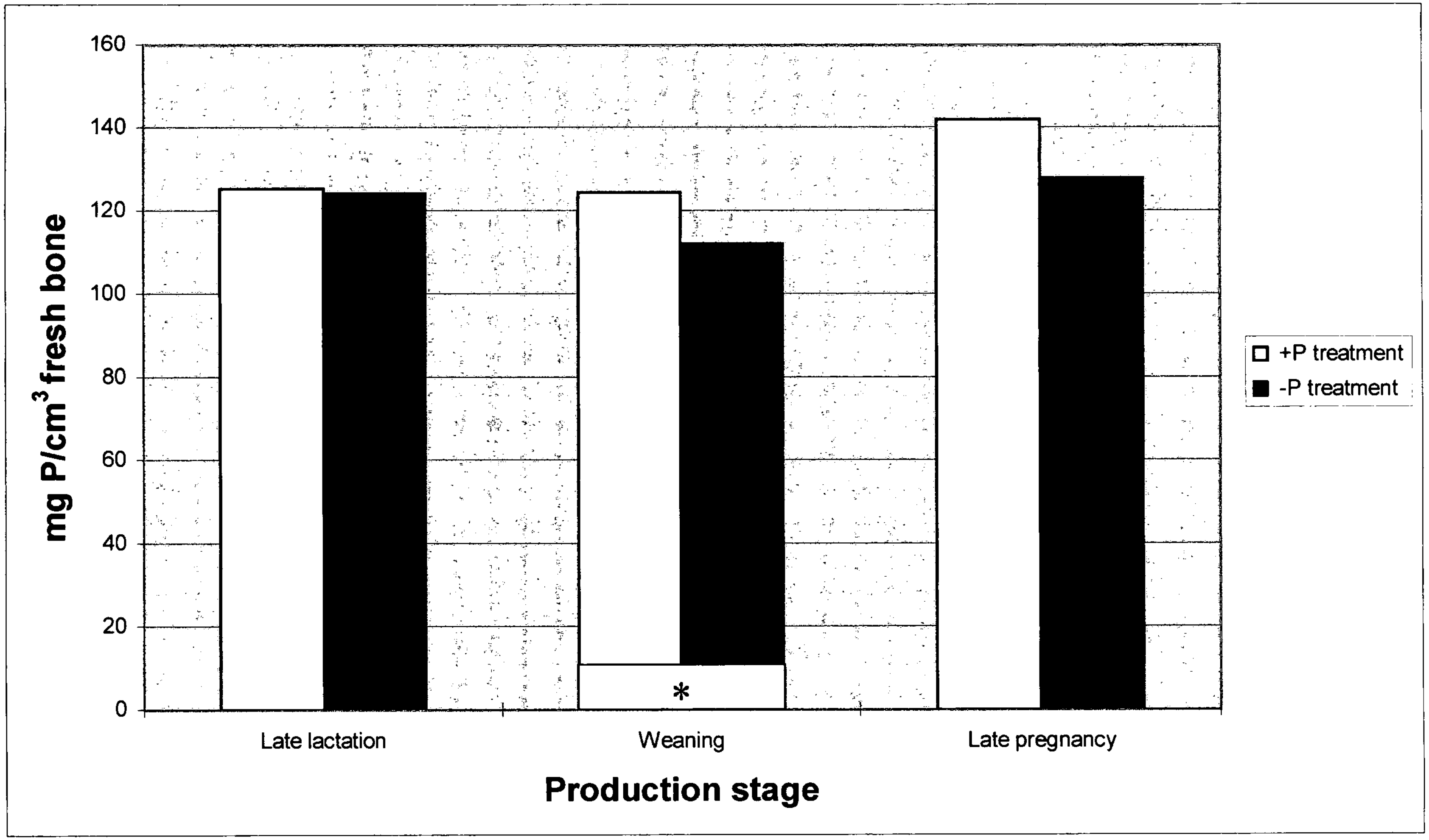

FIGURE 5.2 Phosphorus (P) concentrations of fresh rib bone sampled at specific production stages from cows in the two treatments at Saratoga.

* Averages differ significantly ($P \leq 0.05$) between +P and -P treatments at each interval.

satisfactory towards late pregnancy. With the study at Glen the -P treatment maintained a P level of more than 120 mg P/cm^3 for the rest of the study and there were no advantage in terms of any animal production aspects with P supplementation vs. no P supplementation (Read *et al.*, 1986b; Read, 1984). Seeing that the animals were replaced during January 1993 at Saratoga and the rib bone samples of only one reproduction year was available, it is not known if it would have followed the same tendency as the study at Glen.

The data agree to a large extent with that of a similar study that was conducted at Koopmansfontein (Spangenberg, 1997) for the first reproduction year. The studies at Glen (Read, 1984) and Koopmansfontein (Spangenberg, 1997) and this study at Saratoga followed similar tendencies for the P contents of rib bone of the –P treatment group during the first reproduction year. The P content was in the order of 112 mg/cm^3 fresh bone at weaning and may be regarded as a general indication of P deficiency.

The cows at Glen completely recovered towards late pregnancy (±4 months later) and did not show any signs of a deficiency again (Read, 1984). The +P and -P treatment groups at Koopmansfontein (Spangenberg, 1997) and Saratoga maintained a high salt intake and showed symptoms of stiffness, anorexia and incoordination (see 4.1). The symptoms developed suddenly after free access to licks containing salt by both +P and –P cows, but especially in the -P treatments which received only a salt lick, with cows that died eventually (7 out of 20 - Koopmansfontein; 2 out of 30 - Saratoga). In an adjustment of procedure, the salt intake at Koopmansfontein was then limited to 80 g/cow/day and the cows recovered in terms of body mass, reproduction and P contents of the rib bone. Although, the adjustment was made at Saratoga, 2 cows in the –P treatment did not recover like the others and eventually died in December 1992. However, apparent recovery at Koopmansfontein took a long time, about three years. It is important to note that these symptoms did not correspond with the classical symptoms of P deficiency that were observed at Armoedsvlakte (Read, 1984). Such animals showed symptoms of deformity and up and down (seesaw) cycles of production, which are linked to physiological status and a slow erosion-effect as a result of depletion and repletion of body reserves.

Based on the discussion above, the hypothesis arose that the animals at Koopmansfontein were negatively influenced through an over indulgence of salt, rather than a typical P deficiency (De Waal, 1994a; Spangenberg, 1997). This hypothesis seems to have been confirmed by the observations and data at Saratoga. According to Table 5.1 and Figure 5.2, a decrease in bone P content was not reflected in the drop in SG as found by Read *et al.* (1986b).

5.1.1.3 Ca content and the Ca:P ratio of rib bone

Significant ($P \leq 0.05$) differences for Ca content of fresh bone (Table 5.1) occurred only at late lactation between the +P and -P treatments, as illustrated in Figure 5.3. Again, for the duration of the first phase of the trial, the +P cows had a higher Ca content of fresh bone compared to the –P cows.

The Ca:P ratio in bone in this study differed markedly from the accepted ratio of 2:1 (ARC, 1965). The average Ca:P ratio ranged between 1.7 and 1.6 for the +P and -P treatments (Table 5.1). Moreover, the Ca:P ratio showed a consistent decrease for both the treatments. This is also in contrast with the findings of Read *et al.* (1986b), where this ratio, even with an extreme P deficiency, did not deviate much from the theoretical ratio of 2 Ca:1 P. The data at Saratoga is in agreement with those obtained at Koopmansfontein (Spangenberg, 1997).

5.1.1.4 Mg content of rib bone

According to Table 5.1 and Figure 5.4, the +P and -P treatments differed significantly ($P \leq 0.05$) for Mg in bone at late lactation and at weaning. Means showed an increasing concentration of bone Mg from the first to the second sampling, followed by a decreasing effect of Mg bone from the second to the third sampling. Jacobson *et al.* (1972) stated

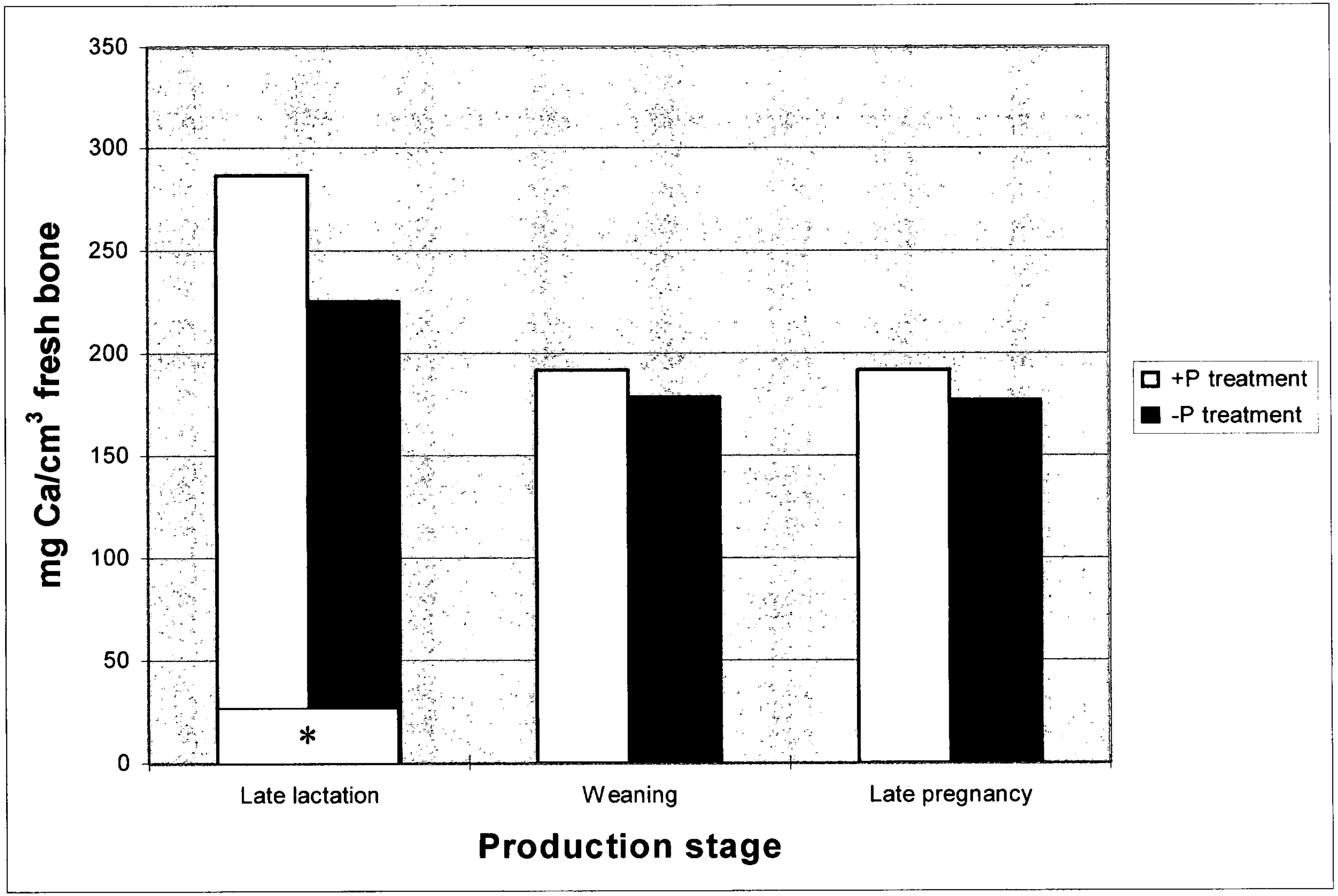

FIGURE 5.3 Calcium (Ca) concentrations of fresh rib bone sampled at specific production stages from cows in the two treatments at Saratoga.
* Averages differ significantly ($P \leq 0.05$) between +P and –P treatments at each interval.

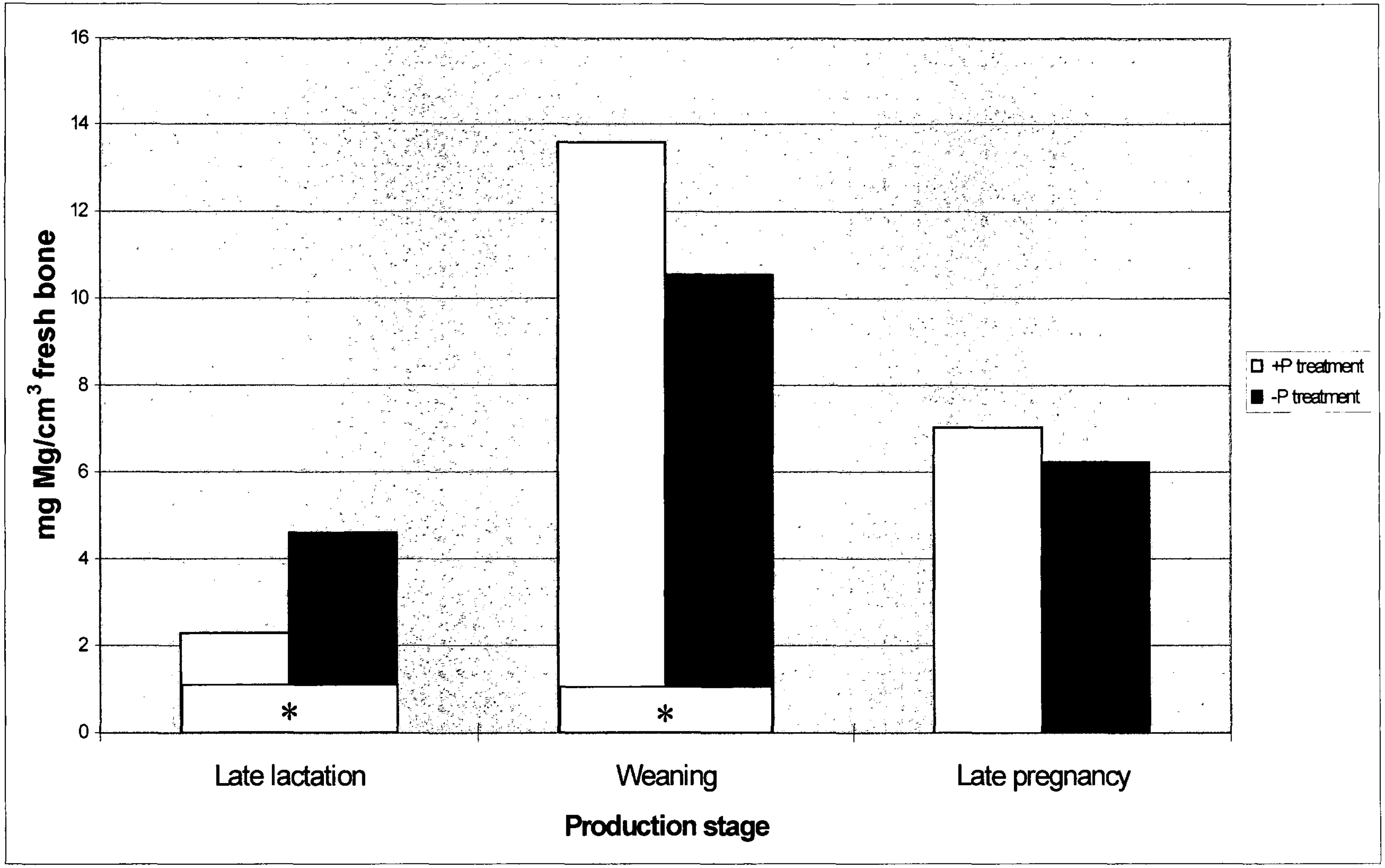

FIGURE 5.4 Magnesium (Mg) concentrations of fresh rib bone sampled at specific production stages from cows in the two treatments at Saratoga.
* Averages differ significantly ($P \leq 0.05$) between +P and –P treatments at each interval.

that the rib bone Mg reserves seem to have been depleted and repleted together with bone P and Ca, probably because of the interrelationship among these minerals.

Contrary to previous studies (Read, 1984; Groenewald, 1986; De Waal & Koekemoer, 1997), no consistent positive interrelationship between Ca and Mg, regarding their mobilisation in bone, was observed with the study at Vaalharts (Spangenberg, 1997). This has also been the case at Saratoga. Although Read (1984) found a positive interrelationship between P, Ca and Mg at Armoedsvlakte, such an interrelationship apparently did not exist at Glen. The Mg content of the rib bone in the present study also agrees with those at Koopmansfontein (Spangenberg, 1997).

5.1.2 Blood plasma

The average mineral concentrations in blood plasma sampled at specific production stages (late lactation, weaning and late pregnancy) from cows in the different treatments, are illustrated in Table 5.3. In addition to the mineral content and SG of rib bone as an indicator of P status, the mineral content of blood plasma also served as an indicator.

Read *et al.* (1986d) pointed out that most critical levels (those levels above or below the values associated with specific clinical signs) reported in the literature (Table 5.2), are based on serum analyses, which have been used for comparison with plasma analyses without correcting for the plasma proteins. It is however not convenient to correct for the plasma protein fraction and, therefore, the plasma P_i is used. This procedure was again adopted in this study because mineral concentrations were determined in blood plasma according to the recommendations of Little *et al.* (1971) and similar to the analyses which have been widely used in several previous studies (De Waal, 1979; Read *et al.*, 1986a,d; Groenewald, 1986; De Waal & Koekemoer, 1997; Spangenberg, 1997). Therefore, values presented here may differ from other published values, which are based on analysis of blood serum.

TABLE 5.2 Some critical levels of blood components (mg/100 ml)

Component	P	Ca	Mg	Reference
Plasma	-	-	1.7-3.0	Wilson (1964)[2]
Plasma	>4.5	-	>1.8	Underwood (1966)[2]
Blood[1]	4.0-8.0	-	-	Hemingway (1967)[2]
Serum	4.0-7.0	9.0-12.0	-	Simesen (1970)[2,3]
Serum	4.3-7.7	8.7-10.3	2.0-3.0	Payne *et al.* (1973)[3]
Serum	4.0-7.0	8.0-10.0	-	Payne *et al.* (1977)[3]
Plasma	3.6-7.2	8.3-10.2	-	Payne *et al.* (1977)[3]
Plasma	4.0-9.0	9.0-12.0	1.8-3.0	Church (1979)[2]
Serum	4.0-6.0	9.0-11.0	1.8-3.0	Underwood (1981)[3]
Plasma	4.0-8.0	8.0-12.0	2.0-3.0	Read *et al.* (1986d)
Range	**3.6-9.0**	**8.0-12.0**	**1.7-3.0**	

[1] = According to Read (1984) this probably refers to serum.
[2] = As cited by Groenewald (1986).
[3] = As cited by Read *et al.* (1986d).

TABLE 5.3 Average phosphorus (P), calcium (Ca) and magnesium (Mg) contents of the blood plasma samples of the +P and -P cows taken at specific production stages

Variable	+P treatment				-P treatment			
	Late lactation[1]	Weaning[2]	Late pregnancy[3]	Average	Late lactation[1]	Weaning[2]	Late pregnancy[3]	Average
Number (n)	10	10	10	10	10	10	10	10
mg P%	3.3*	NA	5.6*	4.4	1.8*	NA	2.9*	2.4
mg Ca%	8.5*	NA	9.8	9.2	9.7*	NA	9.7	9.7
mg Mg%	2.4	NA	2.3	2.4	2.4	NA	2.3	2.4

1 = 1992-04-21
2 = 1992-06-30
3 = 1992-10-22
* = Averages between treatments in corresponding periods differ significantly (P = 0.05).
NA not available (see text).

It is important to note that no data on blood is available at weaning, because the photospectrometre was defective and not enough blood plasma was available to repeat the analysis.

5.1.2.1 P, Ca and Mg content of blood plasma

The P_i level of blood plasma (Table 5.3) in the +P treatment dropped below the lower critical limit (3.6 mg P/100 ml plasma) during late lactation (Table 5.2), while the P_i levels for the -P treatment were never above the critical limit. This may have been an indication of a P deficiency in the -P treatment group.

The Ca levels of blood plasma did not drop below the critical level (8 mg Ca/100 ml plasma) during late lactation and late pregnancy for both treatments.

Mg levels of blood plasma were never below the critical levels (1.7 mg Mg/100 ml plasma) for all treatments. However, this was not the case at Koopmansfontein and Vaalharts where the Mg levels of blood dropped below the critical levels for all the treatment groups (Spangenberg, 1997).

5.1.2.2 Relationship between P, Ca and Mg

At the first and third interval (late lactation and late pregnancy), the +P treatment had significantly ($P \leq 0.05$) higher P_i levels in blood plasma than the -P treatment. The significantly ($P \leq 0.05$) higher Ca levels in blood plasma of the -P treatment during late lactation correspond to the inverse relationship between Ca and P_i levels of blood plasma (Groenewald, 1986; Read *et al.*, 1986d). There appears to be a tendency for an increased plasma Ca level in compensation for a low P_i level, a tendency also observed by Read *et al.* (1986d), De Waal and Koekemer (1997) and Spangenberg (1997). However, this tendency was only seen in the -P treatment and not in the +P treatment. Underwood (1966) also suggested that this tendency might be a result from both Ca and P_i being resorbed from bone mineral reserves during dietary inadequacies. In the study at Saratoga, a significantly ($P \leq 0.05$) negative correlation ($r = -0.21$) was found between Ca and P in the blood.

The blood plasma Mg concentration did not change much in the two treatments. As was the case with Ca, one must ask whether a higher level of P_i reduces the level of Mg (De Waal & Koekemoer, 1997). The Mg levels of blood plasma were not directly influenced by the changes in P_i levels.

5.2 The mineral content of rib bone and blood

Although the low bone P content of the –P treatment at Saratoga (see 5.1.1.2), suggested a P deficiency of these animals, it might also be hypothetically ascribed to an overindulgence of salt by these animals. Low P content of bone also occurred in the +P treatment, although to a lesser extent. This has also been the case at Koopmansfontein (Spangenberg, 1997).

Aphosphorosis is a condition that results from the effect of resorption and draining of bone mineral reserves, following a seesaw effect which is linked to the physiological status of the cow, eventually causing depletion of bone reserves over a lengthy period of time. Although the symptoms observed in the cows of the –P treatment group at Saratoga showed resemblance with P deficiency symptoms as described by Read (1984) and Spangenberg (1997), the symptoms developed atypically to that of a P deficiency.

- Firstly, the symptoms of anorexia, stiffness and incordination developed rapidly after the trial commenced, with deaths that occurred in the –P treatment.

- Secondly, the sudden decline in body mass of the cows in both the +P and –P treatments.

- Thirdly, the fact that the more dominant cows showed these symptoms first, because they were dominating the lick troughs.

With the trial at Saratoga, cows which were negatively affected by an overindulgence of salt and which showed the same symptoms as the cows at Koopmansfontein never fully recovered, not even when provided with a fully balanced diet and injection with a P substance (H.P. Spangenberg, J.M. van der Heever, H.O. de Waal, E.D. Graupner & J.M. Smith, 1994; unpublished data, as cited by Spangenberg, 1997). This was also contradictory to the known fact that dramatic improvements can be brought about by P supplementation in cattle suffering from P deficiency (Theiler *et al.*, 1927).

Chapter 6

Conclusions

6. Conclusions

6.1 The topographical, climatic and, therefore, vegetation may have had an influence on the outcome of this research. Saratoga is located in the Molopo region with its characteristic deep sandy to loamy sands of aeolian origin, underlain by calcrete which may have had an influence on the response of the cattle to the P supplementation. Furthermore, over the trial period, drought conditions prevailed with low rainfall and, therefore, the quantity and quality of vegetation also ranged from average to poor at the site. Below average conditions were experienced from the start of the trial (April 1992) till September 1992. The first rains occurred in October 1992, followed by good rains in November 1992, suggesting that drought conditions may become less severe. From an animal production point of view very harsh conditions prevailed during the whole trial period at Saratoga. It was assumed that the site was suitable to conduct the trial and that the results would provide answers to the question whether a P deficiency exits on the veld in this part of the Northwest Province.

6.2 From the start of the trial at Saratoga, lick consumption was very high for both the +P and -P treatments. The reason for the voluntary high lick and especially salt consumption at Saratoga is uncertain and might partly be ascribed to the harsh conditions that prevailed when the trial commenced. The veld was not in the usual good condition for summer, due to the low rainfall, and was possibly unable to satisfy the lactating cow's need, which might have been a contributing factor for the higher lick intake during the trial for both treatments.

6.3 At Saratoga, a highly irregular and high (compulsive) intake of especially NaCl might have contributed to the serious body mass losses of cows in both treatments, but especially in the –P treatment group, and the deaths that occurred in the –P treatment group. The desired lick intake, which was set at 80 g NaCl/cow/day for both treatment groups and 6.4 g P/cow/day for the +P treatment, was based on results which were gained at Armoedsvlakte (De Waal *et* *al.*, 1996) and Koopmansfontein (De Waal *et al.*, 1993; unpublished data). The very high and unexpected voluntary lick intake at Saratoga prompted some further adjustment in the way that licks were provided. Therefore, the number of troughs were increased and the weekly allowance of licks for both treatments given in two smaller portions per week. However, the high lick intake persisted.

6.4 The body mass of cows differed non-significantly ($P > 0.05$) between the +P and –P treatment groups over the whole trial period at Saratoga. The +P treatment group averaged a higher body mass compared to the –P treatment group. Although the cows in both treatments, especially the –P cows, experienced a big loss in body mass immediately after the trial commenced, it was partly attributed to a period of drought which coincided with the start of the trial. During this period of extreme drought the cows in both treatments showed signs of stress, but more so in the –P group. The –P cows could also have been negatively affected by an overindulgence of NaCl since the trial commenced. However, the difference between +P and –P treatment groups was significantly ($P < 0.05$) different only from the second (30 June 1992) till the last occasion (5 January 1993) the body mass of the cows were taken. It also seemed if the cows of both treatments were able to recover in terms of body mass after the first rains had occurred in October 1992 and with the effects of the concomitant positive response in veld quality. Although, the cows of the –P treatment group recovered slowly, the recovery of the +P cows was more dramatic.

6.5 A gap between the +P and –P cows widened from the start of the trial (April 1992) until the end (January 1993), regarding body mass in favour of the +P cows. This could be an indication of a P deficiency that developed in the –P treatment as the trial progressed (Spangenberg, 1997).

6.6 It will be more advantageous to weigh the animals on a monthly basis, instead of the periodical weighing as happened in 1992. The mass differences during the trial period can thus be better interpreted in terms of supplemented feeding and seasonal changes in natural grazing.

6.7 The reproductive performance of cows over the trial period at Saratoga, was an important objective to measure the effects of P supplementation. However, as indicated this trial started with cows with calves at foot. Therefore, very little can be said during this first phase of the trial on reproduction, except that it started with 30 cows with calves at foot in each of the +P and –P treatment and that all 30 calves in both +P and –P treatment groups were weaned successfully.

6.8 It is not a standard practise to record birth mass in the commercial beef cattle herd at Saratoga, therefore, a birth weight was assumed for the calves in this trial. The results in terms of body mass and ADG between the two treatments, throughout the entire first phase of the trial, were non-significantly ($P < 0.05$) different. The differences that may have occurred could not be ascribed to the effect of the treatment. However, the performance of calves whose dams seemed to have suffered from P deficiency, showed that in times of nutrient deficiencies the cow sacrifices herself to shield the calf from such deficiencies, ensuring the existence of the species. It also seems as if the effects of supplementation on the cows were not passed on to their calves. Valuable information was gathered in this first phase of the trial, which ensured the implementation of further corrective procedures in the following years of the trial at Saratoga (De Waal, 1998; personal communication).

6.9 The fact that the mineral matter is lost from bone by means of resorption, thereby increasing bone's porosity, which is reflected in a reduced SG, was again confirmed at Saratoga. The SG differed significantly ($P < 0.05$) for +P vs. –P cows at weaning. This suggested that a significantly ($P < 0.05$) higher level of bone demineralisation occurred in the –P treatment group. This also corresponds with the results of Read (1984) at Glen.

6.10 The body mass loss of cows in both treatments occurred very rapidly after the trial commenced. Clinical symptoms, notably stiffness, anorexia and incoordination developed rapidly in the –P cows, followed by deaths a few month later after the start of the trial. At this stage in June 1992 (30-06-1992), the –P cows averaged only 112.1 mg P/cm^3 of fresh bone at weaning and recovered satisfactory towards late pregnancy. This may be regarded as a general indication of P deficiency. The –P cows maintained a significantly ($P < 0.05$) lower P content of fresh bone compared to the +P cows over the trial period. These low bone P content values were reflected in the poor production of the –P treatment group. However, the –P treatment group at Saratoga averaged a lower P, Ca and Mg content of bone, compared to the +P treatment group, over the whole trial period.

6.11 The Ca:P ratio in bone differed from the accepted ratio of 2:1 (ARC, 1965). The average ratio ranged between 1.7 and 1.6 to 1 for the +P and –P treatments. This is also in contrast with the findings of Read *et al.* (1986b), where this ratio, even with an extreme P deficiency, did not deviate much from ratio of 2Ca: 1P.

6.12 Blood plasma P concentration was indicative of the P intake of animals, but not necessarily of their P status. The rib bone P concentration still remains the more accurate indicator of the mineral reserves in the animal.

6.13 The results at Saratoga showed the need for further and more detailed research concerning not only P, but NaCl as well. It will be advantageous to incorporate a zero supplementation treatment, to help clarify the NaCl issue.

6.14 According to the research done at Saratoga, it is clear that the cows suffered from a P deficiency when not supplemented with P on the veld. However, there are strong indications that the suspected effects of high levels of NaCl confound the results. These aspects require further investigation.

Chapter 7

Abstract/Samevatting

7. Abstract

An investigation was launched to determine the influence of the P status of grazing beef cattle on their production and reproduction on the veld of Saratoga in the Northwest Province. The study at this site dealt with the following aspects:

- topographical, climatic and nutritional factors which might have had an influence on the study;
- the lick intake and the effects of P supplementation on the productive performance of beef cows;
- the effect of P supplementation on the reproductive performance of beef cows and calf performance; and
- rib bone and blood as indicators of the P status of the reproducing beef cows.

The main treatments (+P and –P) basically comprised 60 beef cattle type cows. These cows were divided in two separate groups of 30 each. The +P cows were supplemented with P and salt in a lick, while the –P cows received only a salt lick.

An extremely poor rainfall during a very dry 1992, had the effect that the quantity and quality of vegetation ranged from average to poor at the site. The lick intake was extremely high with the start of the trial at Saratoga. The intake of the +P treatment group later decreased to the acceptable level of 80 g NaCl – and 6 g P/cow/day but the –P treatment group was still maintaining a high salt lick intake.

The production of the cows, in the +P treatment over the trial period at Saratoga was significantly ($P < 0.05$) better compared to the –P treatment cows. The +P cows achievement in terms of the growth of their calves was in general better compared to the calves of the –P cows. However, there was no difference in terms of reproduction between the treatments during the whole period of the trial. When considering all measured variables, the –P cows realised the poorest performance in the trial at Saratoga.

The results suggested that the –P cows could not produce without receiving a certain amount of supplementary P in their diet, especially when drought conditions prevailed.

At Saratoga there was a rapid loss of weight of the cows in both treatments shortly after the trial commenced. The –P cows very rapidly developed clinical symptoms, notably stiffness, anorexia and discoordination, followed with deaths a few months after the trial started. At this stage (weaning) the –P cows averaged only 112.1 mg P/cm^3, which is a significantly ($P < 0.05$) lower P content of fresh bone compared with the +P cows (124.4 mg P/cm^3). This is thus an indication of a P deficiency, as we assured at this stage (weaning). However, the average of the P content of fresh bone over the trial period showed no indication of a P deficiency between the two treatments.

The purpose of this study was to determine if a P deficiency exists at Saratoga in the Molopo. Although, the results of the trial led to the hypothesis that an excessive intake of NaCl may induce a P deficiency in ruminants, as could have been the case in the –P treatment group at Saratoga, no clear answers were provided by the trial during the first phase of investigation. According to the results further and more detailed research is needed, concerning not only P but NaCl as well. However, in the interim it must be accepted that the cows suffered from a P deficiency when not supplemented with P on the veld and it will be wise to provide some P especially when extreme drought conditions prevail.

Keywords: Phosphorous, Supplementation, Beef cattle, Reproduction, Veld, Grazing ruminants, Bone, Blood, Biopsies, Salt intake.

7. Samevatting

'n Ondersoek is ingestel om die invloed van die P-status van weidende vleisbeeste op hul produksie en reproduksie op die veld van Saratoga in die Noordwes Provinsie te bepaal. Die studie by die lokaliteit het die volgende aspekte aangespreek:

- topografie, klimatologiese en voedingsaspekte wat die studie kon beïnvloed;
- die lekinname en die effek van P-aanvulling op die produksievermoë van vleisbeeskoeie;
- die effek van P-aanvulling op die reproduksie van die vleisbeeskoeie en prestasie van kalwers; en
- ribbebeen en bloed as indikators van die P-status van die reproduserende vleisbeeskoeie.

Die hoofbehandelings (+P en –P) het basies uit 60 vleisbeestipe koeie bestaan. Hierdie koeie is in twee afsonderlike groepe van 30 elk verdeel. Die +P koeie het P en sout in 'n lek ontvang en die –P koeie slegs 'n soutlek.

'n Uiterse swak verspreiding van die reënval gedurende 'n baie droë 1992, het die gevolg gehad dat die kwantiteit en kwaliteit van die veld gewissel het van gemiddeld tot swak. Die lekinname was uiters hoog met die aanvang van die proef op Saratoga. Die inname van die +P groep het egter later gedaal tot die aanvaarbare vlak van 80 g NaCl – en 6 g P per koei per dag inteenstelling met die –P groep wat nog steeds 'n hoë inname gehandhaaf het.

Die koeie in die +P behandeling op Saratoga se prestasie oor die proefperiode, in terme van produksie was betekenisvol ($P < 0.05$) beter vergeleke met dié van die –P behandeling koeie. Die +P koeie se prestasie in terme van die prestasie van hul kalwers was ook oor die algemeen beter in vergelyking met dié van die –P behandeling. Alhoewel daar oor die volle periode van die proef geen verskil was, in terme van reproduksie tussen die behandelings nie. As alle gemete veranderlikes in ag geneem word, het die –P koeie die swakste gevaar in die proef op Saratoga. Uit al die resultate het dit egter geblyk dat die -P koeie nie kon presteer, sonder die aanvulling van 'n sekere hoeveelheid P in hul dieët nie, veral wanneer droogte toestande geheers het.

Op Saratoga het daar 'n skielike massaverlies van die koeie in beide die +P en –P behandeling, kort na die aanvang van die proef, voorgekom. Die –P koeie het skielik kliniese simptome naamlik, styfheid, anoreksia en inkoördinasie ontwikkel, gevolg deur vrektes 'n paar maande na aanvang van die studie. Op die stadium (speen) het die –P koeie 'n gemiddeld van slegs 112.1 mg P/cm^3 gehad, wat 'n betekenisvolle ($P < 0.05$) laer been inhoud het in vergelyking met die +P koeie (124.4 mg P/cm^3). Dit is dus 'n indikasie van 'n P-tekort, net vir die stadium (speen). Alhoewel die totale gemiddeld van die P-inhoud van been geen indikasie van 'n P-tekort, tussen die behandelings getoon het nie.

Die doel van die studie was om te bepaal of daar 'n P-gebrek op Saratoga in die Molopo bestaan. Alhoewel die resultate van die proef aanleiding gegee het tot die hipotese dat 'n P-tekort by herkouers geïnduseer kan word deur 'n oorinname van NaCl, soos wat die geval was met die –P koeie op Saratoga is geen duidelike antwoord deur die proef gedurende die eerste fase van die ondersoek verskaf nie. Na aanleiding van die resultate het 'n behoefte vir verdere en meer gedetaileerde ondersoeke ten opsigte van die aanvulling van P en NaCl, ontstaan. In die tussentyd moet egter aanvaar word dat die koeie 'n P-tekort getoon het in die afwesigheid van P-aanvulling op die veld en dat dit wys sou wees om P in ekstreme droogtetoestande te verskaf.

Literature Cited

Literature Cited

ACOCKS, J.P.H., 1988. Veld types of South Africa. 3ed Ed. *Mem. Bot. Surv. S. Afr.* No 57. Pretoria: Government Printer.

ARC (AGRICULTURAL RESEARCH COUNCIL), 1965. The nutrient requirements of farm livestock. No. 2. Ruminants. Technical reviews and summaries. HMSO, London.

BELONJE, P.C. & VAN DEN BERG, A., 1983. Failure of bone phosphorus to indicate dietary intake of phosphorus by sheep. *Onderstepoort J. Vet. Res. 50, 1.*

BERGER, L.L., 1992. Salt-regulated supplements enhance steer performance. *Feedstuffs,* June. 22, 11.

BISSCHOP, J.H.R., 1964. Feeding phosphates to cattle. S.A. Dept. A.T.S., Science Bulletin 365, Pretoria.

COHEN, R.D.H., 1975. Phosphorus and the grazing ruminant. *Wld. Rev. Anim. Prod.* 2, 26.

CHURCH, D.C., 1984. The nutrients, their metabolism and feeding standards. In: Livestock Feeds and Feeding (second Ed.). O & B Books, Inc., Oregon, U.S.A. p. 25.

DE WAAL, H.O., 1979. Die voedingswaarde van veldweiding van die sentrale Oranje-Vrystaat vir skape met spesiale verwysing na die rol van proteien- en fosforaanvullings. M.Sc. (Agric)- verhandeling, Universiteit van Stellenbosch.

DE WAAL, H.O., 1990. Animal production from native pasture (veld) in the Free State Region - A perspective of the grazing ruminant. *S. Afr. J. Anim. Sci.* 20,

1.

DE WAAL, H.O., 1994a. Effects of sodium chloride (salt) on grazing ruminants. *AFMA MATRIX.* (1), 15.

DE WAAL, H.O., 1994b. The effects of long-term variation in rainfall and dry matter production of veld on the financial position of a beef weaner enterprise. *S. Afr. J. Anim. Sci.* 24, 113.

DE WAAL, H.O. & BIEL, L.C., 1989a Supplementation of lactating Dorper and Merino ewes on *Themeda-Cymbopogon* veld. 1. Body mass changes of ewes and their lambs. *S. Afr. J. Anim. Sci.* 19, 141.

DE WAAL, H.O. & BIEL, L.C., 1989b. Supplementation of lactating Dorper and Merino ewes on *Themeda-Cymbopogon* veld. 2. Diet quality and feed intake. *S. Afr. J. Anim. Sci.* 19, 148.

DE WAAL, H.O., BAARD, MARGARIETHA, A. & ENGELS, E.A.N., 1989a. Effects of sodium chloride on sheep. 1. Diet composition, body mass changes and wool production of young Merino weathers grazing native pasture. *S. Afr. J. Anim. Sci.,* 19, 27.

DE WAAL, H.O., BAARD, MARGARIETHA, A. & ENGELS, E.A.N., 1989b. Effects of sodium chloride on sheep. 2. Voluntary feed intake and changes in certain rumen parameters of young Merino weathers grazing native pasture. *S. Afr. J. Anim. Sci.* 19, 34.

DE WAAL, H.O., ENGELS, E.A.N., VAN DER MERWE, F.J. & BIEL, L.C., 1981. Supplementing sheep with protein and phosphorus on native pasture of the central Orange Free State. 2. Feed intake, mass changes and wool production. *S. Afr. J. Anim. Sci.* 11, 217.

DE WAAL, H.O. & KOEKEMOER, G.J., 1997. Blood, rib bone and rumen fluid as indicators of phosphorus status of grazing beef cows supplemented with different levels of phosphorus at Armoedsvlakte. *S. Afr. J. Anim. Sci.* 27, 76.

DE WAAL, H.O., RANDALL, J.H. & KOEKEMOER, G.J., 1996. The effects of phosphorus supplementation on body mass and reproduction of grazing beef cows supplemented with different levels of phosphorus at Armoedsvlakte. *S. Afr. J. Anim. Sci.* 26. 2.

DU TOIT, P.J., LOUW, J.A. & MALAN, A.I., 1940. A study of the mineral content and nutritional value of natural pastures in the Uion of South Africa. *Onderstepoort J. Vet. Sci.* 14, 123.

ELLIOTT, R.C., 1964. Some nutritional factors influencing the productivity of beef cattle in Southern Rhodesia with particular reference to the effect of seasonal changes in the composition of veld, provision of nutritional supplements to veld grazing and observations of maintenance protein requirements of two African cattle. Ph.D Thesis, University of Londen.

ENGELS, E.A.N., DE WAAL, H.O., BIEL, L.C. & MALAN, A., 1981. Practical implications of the effect of drying and treatment on nitrogen content and *in vitro* digestibility of samples collected by oesophageally fistulated animals. *S. Afr. J. Anim. Sci.* 11, 247.

ENGELS, E.A.N. & VAN DER MERWE, F.J., 1967. Application of an *in vitro* technique to South African forages with special references to the effect of certain factors on results. *S. Afr. J. Agric. Sci.* 10, 983.

FAURE, A.S., MINNAAR, G.J. & BURGER, F.J.L., 1985. Phosphorus supplementation of Karakul sheep grazing natural pasture. *S. Afr. J. Anim. Sci.* 15, 33.

FOURIE, J.H. & DU TOIT, P.F., 1983. Weidingstudies in die Vrystaatstreek: Die bepaling van veldtoestand. *Glen Agric* 12: 11.

GANONG, W.F., 1977. In: Review of Medical Physiology (8th Ed.). Large Medical Publications, California, 294.

GARTNER, R.J.W., McLEAN, R.W., LITTLE, D.A. & WINKS, L., 1980. Mineral deficiencies limiting production of ruminants grazing tropical pastures in Australia. *Trop. Grassld.* 14, 266.

GROENEWALD, I.B., 1986. Die invloed van stikstof -, energie -en fosforbevattende lekaanvullings op die produksie- en reproduksievermoë van koeie op natuurlike weiding. Ph.D proefskrif, Universiteit van die Oranje-Vrystaat.

HEMMINGWAY, R.G., 1967. Phosphorus and the ruminant. *Outlook on Agriculture* 5, 172.

HODGSON, J., 1982. Influence of sward characteristics on diet selection and herbage intake by the grazing animal. In: Nutritional limits to animal production from pastures. Ed. Hacher, J.B., Farnham Royal. UK. CAB, 153.

HODGSON, J. & RODRIGUEZ, J.M., 1971. The measurement of herbage intake in grazing studies. *A. Rep. Grassld. Res. Inst.* 1970, 132.

JACOBSON, D.R., HEMKEN, R.W., BUTTON, F.S. & HATTON, R.H., 1972. Mineral nutrition, calcium, phosphorus, magnesium and potassium interrelationship. *J. Dairy Sci.* 55, 935.

LITTLE, D.A., 1972. Bone biopsy in cattle and sheep for studies of phosphorus status. *Aust. Vet. J.* 48. 668.

LITTLE, D.A., 1975. Effects of dry season supplements of protein and phosphorus to pregnant cows on the incidence of first postpartum oestrus. *Aust. J. exp. Agric. Anim. Husb.* 15, 25.

LITTLE, D.A., 1982. Utilisation of minerals. In: Nutritional Limits to Animal Production from Pastures. Ed. Hacker, J.B., Commonwealth Agricultural Bureax, Farnham Royal, UK. p. 259.

LITTLE, D.A., McLEAN, R.W. & WINTER, W.H., 1977. Prediction of the phoshorus content of herbage consumed by grazing cattle. *J. Agric. Sci. Camb.* 88, 533.

LITTLE, D.A. & McMENIMAN, N.P., 1973. Variation in bone composition of grazing sheep in South-Western Queensland, related to lactation and type of country. *Aust. J. exp. Agric. Anim. Husb.* 13,229.

LITTLE, D.A. & MINSON, D.J., 1977. Variation in the phosphorus content of bone samples obtained from the last three ribs of cattle. *Res. Vet. Sci.* 23, 393.

LITTLE, D.A. & RATCHIFF, D., 1979. Phosphorus content of bovine rib: influence of earlier biopsy of the same rib. *Res. Vet. Sci.* 27, 239.

LITTLE, D.A., ROBINSON, P.J., PLAYNE, M.J. & HAYDOCK, K.P., 1971. Factors affecting blood inorganic phosphorus determinations in cattle. *Aust. vet. J.* 47. 153.

LITTLE, D.A. & SHAW, 1979. Superphosphate and stocking rate effect on a native pasture oversown with Stytosanthes humilis in central coastal Queensland. 5. Bone phosphorus levels in grazing cattle. *Aust. J. exp. Agric. Anim. Husb.* 19, 645.

LOUW, G.N., 1969. The nutritive value of natural grazings in South Africa. *Proc. S. Afr. Soc. Anim. Prod.* 8, 57.

LOUW, G.N., 1978. Die aanwending van voedselhulpbronne vir diereproduksie. *S. Afr. Tydskr. Veek.*8,79.

LOUW, G.N., 1979. An evaluation of the application of stock licks in South Africa. *S. Afr. J. Anim. Sci.* 9 ,133.

LOW, BARRIE, A. & REBELO, A., (TONY) G., 1996. Vegetation of South Africa, Lesotho and Swaziland. Department of Environmental Affairs & Tourism, Pretoria.

MARAIS, P.G., HAYWARD, F.C., JACOBS, G.A., CLOETE, J.A.N. & KOEN, A., 1989. Die invloed van lekaanvullings op produksie en reproduksie van Merinoskape op vier soorte Karooveld. *Karoo Agric.* Vol. 4(2). 11.

MacDONALD, I.W., 1968. The nutrition of grazing ruminants. *Nutr. Abstr. Rev.* 38, 381.

MEISSNER, H.H., HOFMEYER, H.S., VAN RENSBURG, W.J.J. & PIENAAR, J.P., 1983. Classification of livestock for realistic prediction of substition values in terms of biologically defined Large Stock Unit. Tech. Comm. No. 175. Department of Agriculture, Pretoria.

McDOWELL, L.R., CONRAD, J.H. & ELLIS, G.L., 1984. Mineral deficiencies and imbalances, and their diagnosis. In: Herbivore nutrition in the subtropics and tropics. Eds. Gilchirst, F.M.C. & Mackie, R.I. The Science Press, Graighall, South Africa.

NATIONAL RESEARCH COUNCIL, 1984. Nutrient requirements of domestic animals. Nutrient requirements of beef cattle. 9th ed. Washington D.C.: National Academy Press.

READ, MARION V.P., 1984. Animal performance from natural pastures and the effects of phosphorus supplementation. M.Sc. thesis, University of Stellenbosch.

READ, MARION V.P., ENGELS, E.A.N. & SMITH, W.A., 1986a. Phosphorus and the grazing ruminant. 1. The effects of supplementary P on sheep at Armoedsvlakte. *S. Afr. J. Anim. Sci.* 16, 1.

READ, MARION V.P., ENGELS, E.A.N. & SMITH, W.A., 1986b. Phosphorus and the grazing ruminant. 2. The effects of supplementary P on cattle at Glen and Armoedsvlakte. *S. Afr. J. Anim. Sci.* 16, 13.

READ, MARION V.P., ENGELS, E.A.N. & SMITH, W.A., 1986c. Phosphorus and the grazing ruminant. 3. Rib bone samples as an indicator of the P status of cattle. *S. Afr. J. Anim. Sci. 16, 13.*

READ, MARION V.P., ENGELS, E.A.N. & SMITH, W.A., 1986d. Phosphorus and the grazing ruminant. 4. Blood and faecal grab samples as indicators of the P status of cattle. *S. Afr. J. Anim. Sci.* 16, 18.

REID, R.L. & JUNG, G.A., 1982. Problems of animal production from temperate pastures. In: Nutrition limits to animal production from pastures. Ed. Hacker, J.B. Farnham Royal, UK. CAB, 21.

RICHTER, C.G.F., 1991. Gras-bosinteraksie in die bosveldgebiede van noord-kaap. M. Sc. (Agric) tesis, Universiteit van die Oranje-Vrystaat.

SAS, 1988. SAS Procedures Guide, Release 6.03 ed., Cary, NC: SAS Institute Inc.

SAS, 1991. SAS System for Regression, 2nd ed., Cary NC: SAS Institute Inc.

SHUR, W., 1968. Beef cattle respond to supplementation in trial. A.T.S., Science

Bulletin 365.

SPANGENBERG, H.P., 1997. Phosphorus Supplementation to Grazing Beef Cows at Two Sites in the Northern Cape. Ph.D. thesis, University of the Orange Free State.

SPANGENBERG, H.P., DE WAAL, H.O., SMITH, J.M., RICHTER, C.F.G. VAN DEN HEEVER, J.M., SCHOLTZ, H.P.J. & GRAUPNER, E.D., 1995. The effect of phosphorus (P) supplementation on the production and reproduction of cattle on veld at Saratoga in the Northern Cape – with reference to the effect of NaCl supplementation. *Proc. 34th SASAS Congress,* 10-13 April, Bloemfontein, South Africa.

SPANGENBERG, H.P., DE WAAL, H.O. VAN DEN HEEVER, M.J., SCHOLTZ, H.P.J. & SMITH, J.M., 1993. The effect of phosphorus supplementation on the production and reproduction of cattle on veld at Saratoga in the Northern Cape. *Proc. 32th SASAS Congress,* 26-29 April, Wild Coast Sun, Republic of Transkei.

TERNOUTH, J.H., 1997. Phosphorus Metabolism in Ruminant Animals. In: Rumen Microbes and Digestive Physiology in Ruminants. *Japan Sci. Soc. Press.* Tokyo/S Karger, Basel. pp. 167-177.

THEILER, A., 1912. Facts and theories about styfziekte and lamziekte. *Second Report Dir. Vet. Res.* pp, 7-78.

THEILER, A., 1920. The cause and prevention of lamziekte. *J. Dept. Agric. S. Afr.* 1, 221.

THEILER, A., DU TOIT, R.J. & MALAN, A.I., 1937. Studies in mineral metabolism. XXXVII. The influence of variations in the dietary phosphorus and the Ca:P ratio on the production of rickets in cattle. *Onderstepoort J. Vet. Sci. Anim.*

Ind. 8, 375.

THEILER, A & GREEN, H.H., 1932. Aphosphosis in ruminants. *Nutr. Abstr. Rev.* 1, 359.

TILLEY, J.M.A. & TERRY, R.A., 1963. A two-stage technique for the *in vitro* digestion of forage crops. *J. Brit. Grassl. Soc.* 18, 104.

TRUEMAN, K.F. & CLAGUE, D.C., 1978. Sodium chloride poisoning in cattle. *Aust. Vet. J.* 54, 89.

UNDERWOOD, E.J., 1966. In: The mineral nutrition of livestock. Commonwealth Agricultural Bureaux: Farnham Royal, U.K.

UNDERWOOD, E.J., 1981. The mineral nutrition of livestock. Second edition. Commonwealth Agricultural Bureaux: Farnham Royal, U.K.

VAN NIEKERK, B.D.H., 1994. Symposium on the Science of Free Ranging Animals. University of Fort Hare.

WARD, H.K., 1968. Supplementation of beef cows grazing on veld. *Rhod. J. Agric. Res.* 6. 93.