WW-B.DAHL OLD WORLD BLUESTEM IN SUSTAINABLE

SYSTEMS FOR THE TEXAS HIGH PLAINS

by

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ABSTRACT

In regions of highly intensive high input/output agriculture, as the Texas High plains, where cotton is the primary crop, but where also sorghum and wheat are intensively produced, crop-livestock systems are considered an alternative to potentially lessen problems caused by and faced because of this intensity. WW-B. Dahl [WW-B. Dahl; *Bothriochloa bladhii* (Retz.), S.T. Blake] has been one of several introduced grasses in the Texas High Plains as an attempt to diversify agricultural production and alleviate environmental problems such water scarcity and use of potentially dangerous chemicals. This research investigated the value of WW-B. Dahl as forage for grazing steers, the mineral cycling in integrated crop-livestock systems compared with cotton monoculture. An economic comparison of the two systems was included. WW-B. Dahl is the most recently released variety of a group of grasses from the genus *Bothriochloa*. Non-grazed stands of this grass were harvested at monthly intervals or were grazed for 0, 38, and 60 d to determine effects of harvesting strategy on forage yield, botanical and morphological composition, forage quality, and mineral composition in 2001, 2002, and 2003. Each clipping and grazing treatment was replicated three times in a complete randomized block design with a split plot of grazing and clipping treatments. Leaves were higher in concentrations of CP, acid insoluble ash, Ca, S, and Cu and were lower in NDF, hemicellulose, and Zn than stems. By July, non-grazed forage was higher in lignin

than grazed forage. Concentrations of K were higher in leaves than stem by July. Concentrations of K and Cu were higher and Fe was lower in non-grazed than grazed forage but few other differences were observed. Within the growing season, percentage CP decreased while NDF increased but seasonal patterns of change appeared to reflect timing of N fertilization an irrigation water applications, as well as, morphological changes and stage of maturity. Differences in mineral concentration among morphological components were not large enough to reflect differences in morphological fractions due to grazing. WW-B. Dahl is a productive grass, adapted to both hay and grazing but would require supplementation with CP, P, S, Cu, and Zn to meet nutritional needs of most livestock. Soil samples were taken at depth intervals of 0-5, 5-10, and then at 10-cm increments to 60 cm in May 2001 and in December 2003 in the cotton monoculture, rye, wheat, and WW-B. Dahl paddocks including non-grazed areas and areas grazed at different lengths. Averaged over the 6 yr of the project, steers grazed either 0 (non-grazed) or 49, 40, 23, 38, and 60 d in dormant WW-B. Dahl, rye, wheat, and for a short and long term grazing periods in spring growth WW-B. Dahl, respectively. Compaction readings were taken in the same areas where soil samples were collected in the cotton monoculture and the small grains-cotton rotations in February, June, July, and in November following harvest of WW-B. Dahl seed of 2003 and in WW-B. Dahl in June and July of 2002 and in February, June, July, and November following the harvest of WW-B. Dahl seed of 2003. Effects of grazing vs. no-grazing on minerals within the top 5 cm of soil was investigated. Each system, integrated system component, depth and

grazing treatment was replicated three times in a randomized block design with a split-split-plot arrangement of the depth interval and a split-plot arrangement of the system, integrated system component, and grazing treatments. All tested minerals were within the normal ranges required for plant growth. Although some differences in soil minerals, with the exception of Zn, occurred between cotton monoculture and the integrated system, there was little evidence of system or grazing effects and little evidence of change over time. Zinc was higher in non-grazed than grazed soils, regardless of forage species. Grazing generally increased soil compaction but effects disappeared within non-grazed periods. Research is needed to investigate further changes over a longer time period. Four scenarios were simulated for the years 1998 to 2004 in the two systems established. Favorable scenarios for both systems were increased yields and decreased variable costs. The higher returns obtained in the integrated crop-livestock system. Cotton monoculture and cotton in the integrated system produced similar results regarding yields and input use. Livestock is an advantage for the integrated system because it is possible to obtain revenue from both products without increasing the fixed cost of the system.

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LIST OF ABBREVIATIONS

ACP	Available crude protein
ADF	Acid detergent fiber
ADIN	Acid detergent insoluble nitrogen
ADL	Acid detergent lignin
ANI	Average net income
CP	Crude protein
DB	Digestible biomass
DM	Dry matter
DMD	Dry matter digestibility
NDF	Neutral detergent fiber
NRVC	Net return above variable cost
NRTC	Net return above total cost
R	Revenue
SE	Standard error
SVI	Sustainable value index
TNC	Total non-structural carbohydrates
TC	Total cost
VC	Variable cost

PREFACE

Sustainability of Texas High Plains agriculture is challenged among other factors, by the increased depletion of the Ogallala Aquifer. This depletion has resulted in reduced water resources for irrigation, increased pumping depth with a corresponding increase in energy demand, and the high economic risk that cotton as a monoculture imposes on farmers. Alternative approaches including integrated crop-livestock systems may offer sustainable options to agriculture in this region and should be investigated.

This research took a first step in evaluating one such alternative system: a crop-livestock system for the Texas South Plains, using WW-B. Dahl old world bluestem [*Bothriochloa bladhii* (Retz.), S.T. Blake] for grazing by stocker steers and seed production because of its recognized value as forage and for commercialization. Wheat (*Triticum aestivum* L.) and rye (*Secale cereale* L.), grown in alternate year rotation with cotton (*Gossypium hirsutum* L.), provided additional forage while continuing to produce a cotton crop and diversifying income sources.

Due to the nature of the research, this dissertation is presented in independent chapters addressing different aspects of the system's approach as well as each research component. The first chapter looks at the concept of sustainability in agriculture and reviews the systems approach in agriculture, and the components and management strategies of an integrated crop-livestock system in theory and for an already established one. The components are treated independently in order to fully comprehend the reasons why they are part of the system. The second, third, and fourth chapters show agronomic and economic results of the integrated crop-livestock components and the management strategies chosen. The final chapter presents an overall discussion of factors involved in sustainability of the integrated crop-livestock system.

CHAPTER I

SUSTAINABLE AGRICULTURE AND SYSTEMS APPROACH IN AGRICULTURE

> "Understanding something in one way does not preclude understanding it in other ways." Jerome Bruner.

Sustainable agriculture

Sustainable agriculture has as many definitions as authors who have written about the topic; thus, a unique definition that suits all of the expectations of such a term does not exist. Defining what should be considered as sustainable agriculture has become a research problem by itself and will not be addressed in this document; however, some of the diverse approaches regarding this term will be discussed in this section.

Sustainable agriculture in the US was defined in Public Law 101-624, Title XVI, Subtitle A, Section 1683. Under that law,

> [T]he term sustainable agriculture means an integrated system of plant and animal production practices having a site-specific application that will, over the long term:
> 1. satisfy human food and fiber needs;
> 2. enhance environmental quality and the natural resource base upon which the agricultural economy depends;
> 3. make the most efficient use of nonrenewable resources and on-farm resources and integrate, where appropriate, natural biological cycles and controls;

4. sustain the economic viability of farm operations and
5. enhance the quality of life for farmers and society as a whole. (Government Printing Office, 1990).

Such a legal definition, although it helps to clarify policies and government actions and certainly helps final decision-makers (farmers) in their productive processes, does not provide the sociologic framework in which this definition could be applied; and is almost entirely economically oriented. It mentions enhancement of the environment, efficiency of the productive processes and quality of life for society in general regarding financial results but it fails to address the thinking processes surrounding the agriculture activity. Thus, a question arises why farmers choose to be farmers?

Another problem of this definition is that it maintains the idea that farming agriculture should take all the responsibility of environmental damage, therefore, it has to pay the price of any corrective procedure, and, at the same time, be efficient in producing high-value products at low costs. However, other society activities that appear to be unrelated to agriculture may be intimately related and can also be responsible for environmental damage and should certainly be under analysis and regulation. Unfortunately we, as a society, take food and fiber production for granted and demand them to be inexpensive; we are unwilling to sacrifice any aspect of which we consider the minimum life standard. As an example of the later, forage-based beef cattle producers in the Western United States are faced with numerous challenges to remain sustainable and profitable; the most important being convincing the American public that ranchers are sound stewards of public and private lands.

Producers must demonstrate that their production methods do not pose an ecological threat to the landscape (Bowman and Sowell, 2003). The problem is that those who emphasize ecological integrity often look upon human practices as threats; however, human practices can be considered as part of the system (Olesen *et al*., 2000).

Sustainable agriculture is both a philosophy and a system of farming. It has its roots in a set of values that reflects an awareness of both ecological and social realities. It involves design and management procedures that work with natural processes to conserve all resources and minimize waste and environmental damage, while maintaining or improving farm profitability (MacRae, 1991).

The previous definition by using the concept of sustainable agriculture, being a philosophy, vaguely refers to the sociologic component. It is necessary to understand that even if agriculture is a productive activity, which in the prevailing economic system is supposed to be profitable, it is also carried on by human beings that have other requirements that are not necessarily profit related.

Over time an increasing number of researchers, farmers, policy-makers and organizations worldwide have developed a definition that intends to unify diverse elements into a widely adopted, comprehensive, working definition:

> A sustainable agriculture is ecologically sound, economically viable, socially just and humane.
> 1. Ecological soundness. An ecologically sound agriculture also must be resource efficient in order to conserve precious resources, avoid systems toxicity and decrease input costs;
> 2. Economic viability. There should be a positive net return, or at least a balance, in terms of resources expended and returned. Ignored in current accounting are numerous subsidies that

make agriculture appear economically viable and hidden costs such as loss of wildlife and health care costs from chemical exposure. In addition to short-term market factors relating to supply and demand, real viability requires an understanding of a number of other considerations, including relative risk and qualitative factors (security, beauty, satisfaction), which are often ignored in economists' models because they are difficult to quantify;

3. Social Justice. The system must assure that resources and power are distributed equitably so that the basic needs of all are met and their rights are assured. Access to land is necessary in order for a majority of the world's population to escape poverty and grow the food it requires. As important as equitable land tenure is the availability of adequate resources to succeed in this effort, including capital, technical assistance and market opportunities. At the same time, the rights of landless farm workers and the urban poor must be recognized. This requires fair wages, a safe work environment, proper living conditions and the right to nutritious, healthy food;
4. Humaneness. Cultural roots are as important to agriculture as plant roots. Without strong communities and vibrant cultures, agriculture will not flourish. The increasing substitution of the term "agribusiness" for "agriculture" reflects a fundamental shift to a monetized economy in which everything, including human beings, is assigned a certain value. Such a system leads to an increased sense of competition, isolation and alienation. As rural societies break down, their values are lost as the backbone of the larger society. Without such a backbone, agriculture is neither humane nor sustainable. (Jackson *et al*., 1990).

The latter definition addresses social issues and makes them a substantial part of the concept of sustainability. It establishes basic standards by which broadly different agricultural systems and natural conditions can be evaluated and if necessary and/or possible modified in order to create sustainable systems. This definition makes an effort to be fair in allocating responsibilities to society as a whole and not just to one sector of society. In this view, sustainable agriculture becomes a positive scheme regarding the restrictions, problems, traditional wisdom and the latest scientific advances of agricultural systems resulting in integrated, nature-based agro-ecosystems in both the short and long terms. It will be the awareness, empowerment, vision, and values of people, and their appropriate use of science and technology, that will enable us to achieve sustainable agriculture (Hill 1990). Science and technology alone, no matter how powerful they might be, will not be able to achieve sustainability; this will be realized only through our own psychosocial evolution (Hill 1991).

In order to achieve sustainability in agriculture there are many factors to consider, the main being that the crucial elements of the system should be reproduced over time at a rate that depends on previous system states but it has to be socially limited regarding human populations, or human institutions such as the family or rural communities (Olesen *et al*, 2000). Therefore, Sustainable Management means more than continued commodity production at a given rate. It also addresses the social and environmental issues associated with harvesting the resources (Meyer and Helfman, 1993).

In general, sustainability must be defined in terms of ecology and economy. Ecology involves natural aspects of production including crops and animal species to be produced and environmental characteristics such as type of soil, climate, water availability, nutrient cycle, among others some authors refer to this as agronomic processes. “Agronomic sustainability refers to the ability of a tract of land to maintain productivity over a long period of time (Lowrance *et al*., 1986).” Ecology also includes negative or positive effects caused by productive activities on the environment. “Ecological sustainability depends on the maintenance of life-support systems provided by non-agricultural and non-industrial segments of a region (Lowrance *et al*., 1986).” Economy addresses the purpose of production, profitability of the system, and the farmer’s willingness to change the traditional productive system into a “new” sustainable productive system. “Economic sustainability refers to both micro and macroeconomic aspects; the first refers to the ability of the farm, as the basic economic unit, to stay in business; the second refers to factors such as fiscal policies and interest rates which determine the viability of national agriculture systems (Lowrance *et al*., 1986).”

Sustainable agricultural systems should include “cultural practices that maintain profitability through maintaining production while conserving natural resources, taking advantage of biological nutrient cycling (Keeney, 1990).”

Systems approach in agriculture

> "The whole is more that the sum of its parts." Ludwig von Bertalanffy.

Generally, agriculture has been related to the concept of system exclusively regarding the components involved in the production of food or fiber as rigid entities that can be placed any and everywhere without considering anything other than the will of the producer. For a long time, research emphasis in agriculture had focused on improving efficiency, meaning an increase in yield and profit. Use of sophisticated technology, fertilization practices, animal nutrition, and improved varieties (crops and animals) were the main ways to accomplish this. The consequences of this view are now being exposed in the form of environmental deterioration and the cost of remediation when possible. Low yields and social problems are forcing all sectors involved in agricultural activities to rush for immediate solutions ignoring mid-term and long-term effects. Amid the general pool of solutions, sustainable agriculture is probably the most mentioned, researched, and analyzed. To address sustainable agriculture, a systems approach should be followed; under this approach, the system becomes the unit of study and systems theory the main course of action. A system is defined as "…an entity which maintains its existence through the mutual interaction of its parts (Bertalanffy, 1968)." In biological sciences, systems are considered as open entities because they interact with other systems outside of themselves, therefore, accounting for the possibility of a particular system being a component of a bigger system.

Looking more closely at the environment of a system, we see that it too consists of systems interacting with their environments. With respect to the whole, the parts are seen as subsystems; with respect to the parts, the whole is seen as a super-system. Looking at the super-system as a whole, there is no need to be aware of all its parts. It is possible just to look at its total input and total output without worrying which part of the input goes to which subsystem (Heylighen, 2000).

In agriculture, the concept of system accounts for relationships occurring among components that, however present, could remain unexplained but that are essential for the proper functioning of the system. The environment interacts with the system not only determining specifications of some of the components, but most of the time throughout development and use of site-specific technology in an attempt to make the output production more efficient.

Regarding sustainable agriculture, systems theory is defined as "…the interdisciplinary study of the abstract organization of phenomena, independent of their substance, type or spatial or temporal scale of existence. It investigates both the principles common to all complex entities, and the (usually mathematical) models which can be used to describe them (Heylighen, 2000)."

The systems approach integrates the analytic method regarding relationships among system's components and the synthetic method regarding specific processes occurring within components, thus, encompassing both holism and reductionism. Systems analysis, developed independently of systems theory, applies systems principles to aid a decision-maker with problems of identifying, reconstructing, optimizing, and controlling a system (usually a socio-technical organization), while taking into account multiple objectives, constraints and resources (Heylighen and Joslyn, 1992). It aims to specify possible courses of action, together with their risks, costs and benefits (Heylighen and Joslyn, 1992).

In conjunction, these definitions establish a theoretical framework to approach sustainable agriculture from academic and research interests but also facilitate the possibility to transfer knowledge achieved through them and make agricultural systems a practical activity, which should be at last, the ultimate objective.

There are many examples of how a systems approach is implemented in agriculture in order to make it sustainable; some studies involve only one agricultural process; either crop or livestock production.

Public Law 101-624 Title XVI, Subtitle B. Sec. 1627 defines Integrated Crop Management as "…the crop production management system that integrated all controllable factors for long-term sustained productivity, profitability and ecological soundness"; the same law Title XVI, Subtitle B. Sec. 1619 defines Integrated Resource Management as "…the livestock production management system which utilizes an interdisciplinary system approach that integrates all controllable practices to provide long-term sustained productivity and profitable production of safe and wholesome food in an environmentally sound manner" (Government Printing Office, 1990).

There are more complex productive systems which include a combination of agricultural activities (beef systems, dairy systems, grazing systems, crop-forage-livestock systems).

Public Law 101-624, Title XVI, Subtitle B. Sec. 1627 defines Integrated Management Systems:

> As the agricultural production management system that utilizes an interdisciplinary system approach to integrate all controllable practices

> to provide long-term sustained productivity and profitable production of safe and wholesome food in an environmentally sound manner. It includes both Integrated Crop Management and Integrated Resource Management (Government Printing Office, 1990).

Interactions among components are also a target when a systems approach is applied; in this case management strategies are the topics under study and they help to establish what are called the Best Management Practices.

Another way to look at a systems approach is from the domain of a single operation, whether considering its size or not, to the domain of a whole region or country. It is opportune to have in mind that the majority of the studies on sustainable agriculture still emphasize the farmer's economic welfare as an indication of success. Nevertheless, the objective ought to be a multidisciplinary integrative approach.

Analyzing agriculture as a hierarchical system is the appropriate way to incorporate different concepts of sustainability. Under this idea there are critical constraints at different scales of the agricultural hierarchy. Agronomic constraints are most important at the field scale; microeconomic constraints are dominant at the farm scale; ecological constraints override at the watershed or landscape scale; and macroeconomic constraints are foremost at the regional and national scale (Lowrance *et al*., 1986).

When analyzing cropping systems in the Great Plains during the 20th century the conclusion reached was that there is low or inexistent information adequately comprehensive and holistic of crop production and soils for producers to make critical decisions to remain sustainable (Tanaka *et al*., 2002). As an alternative solution a dynamic cropping systems approach was suggested. This is a long-term strategy of annual crop sequencing that optimizes crop and soil use options and the attainment of production, economic, and resource conservation goals by using sound ecological management principles. Key factors considered for this were: diversity, adaptability, reduced input cost, multiple enterprise systems, and awareness of environment and information. This approach relies on multidirectional flow of information among research, extension, and producers. It provides producers with management flexibility for developing their own long-term sustainable system (Tanaka *et al*., 2002).

Integrated farming systems models were tested for several years at the research farm of the Department of Agronomy, Chaudhary Charan Singh Haryana Agricultural University in Hisar, India since 1984-85 by a multi-disciplinary team of research scientists from agronomy, animal sciences, economics and statistics. Some studies were carried out on 1.0 ha, 0.6 ha, 0.4 ha irrigated land holdings and 1.5 ha holding and on grazing under dry land conditions to compare integrated mixed farming systems models with arable farming systems The mixed farming systems consisted of either crossbred cows [Hariana (*Bos indicus* L.; local breed) x Holstein/Jersey (*Bos taurus* L.)] or buffaloes (Murrah breed; *Bubalus bubalus* L.) and arable farming without any milch animal or with one milch animal (farmer’s practice). For relative economic analysis during different years cost of inputs and outputs at market prices prevailing in the year were considered and net income and a Link Relative Index was worked out (Singh, 2002).

The results of more than 15 years of investigation on the development of suitable farming systems for semi-arid tropical situations in Haryana, India, indicated that integration of various enterprises on various sizes of land holdings tended to be more profitable and to generate more employment than arable farming systems under small land holdings for irrigated and dry land conditions (Singh, 2002). However, from the data accumulated over time it was not possible to draw conclusion regarding sustainability of the farming systems. Therefore, in order to evaluate those farming system models on the basis of their sustainability it was necessary to construct a sustainable value index (SVI) for each farming system model. SVI is the ratio of absolute value of the difference of Average Net Income (ANI) from 1.96 times standard deviation of ANI's to the maximum net income in the whole period. The value of SVI calculated by this formula lies between 0 and 1; a value of SVI near to zero given by that model is not sustainable while a value of SVI near to one suggests that model is sustainable.

The results of SVI indicate that farming systems of arable land with one crossbred cow on 0.4 ha were the most sustainable followed by farming systems of arable land without animals on 0.6 ha, farming systems of arable land on 0.4 ha, farming systems of mixed land of 1 crossbred cow on 1.0 ha and farming systems of arable land with 1 crossbred cow on 0.6 ha. Better sustainability of smaller farming systems may be explained due to the fact that they are managed in a better way which improves the productivity and efficiency (Singh *et al*., 2002).

In the southeastern United States the hypothesis that diversified and integrated production systems using agroforestry on small farms can help farmers remain competitive, ensure appropriate land use and cultural transitions, as well as provide environmental amelioration and, thus, societal benefit was proposed. In this region, agroforestry is being promoted through inter-institutional collaboration and extension activities as a way to diversify and intensify farm system management. From data collected by the states of Alabama, Florida, and Georgia it can be inferred that while farmers are aware of the benefits of such systems, lack of familiarity with practices and lack of convincing demonstrations of the practices are the major constraints to adopting agroforestry in the region (Workman and Nair, 2002).

Components of crop-forage-livestock systems

Despite the simplicity of the definitions provided in the previous section, forage-livestock systems are "… the integrated combination of animal, plant, soil and other environmental components managed to achieve a productive agro ecosystem (Allen and Cheney, 1995)." If a crop component is added to the equation, such systems are probably one of the more complex systems in agriculture. Difficulty arises because its design and operation requires synchronization of several subsystems with very specific necessities. Forage production should occur on time to feed livestock that should meet certain market needs but that also should be profitable enough to account for all the costs implicit in the forage and livestock production; forages are an intermediate but indispensable product that frequently do not produce any byproduct that accounts for part of the cost of them. Also at least some of the forage production must be such that allows the same piece of land to be used by the cropping activity besides the area totally dedicated to crops; otherwise the “system” would just consist of adjacent pieces of land and the interactivity among them would be more difficult to accomplish. One of the objectives of this kind of system is to use the land efficiently at its maximum capacity without damaging it. In order to understand and to make the most of these systems it is important to know in detail all aspects involved in them, although to define the system these factors must be performing together. These systems, if managed correctly, would be a viable alternative in areas where traditional systems are no longer efficient.

The starting point is to know the productive framework of the system. The soil type and climate could be the most important factors and are the given conditions to which agriculture should be adapted. The only way to profit from natural factors is to take them into account and to know them as well as possible. The second point is to know what plant species could be produced in this framework either as crop or forage. The next point is to know what kind of livestock can graze this forage successfully. Based on these factors, management strategies are defined. Economic profitability of the system and the effectiveness of it in the chosen place should be evaluated at every step and should take into consideration the cost of any impact the system can have on the environment. The last point, but no less important is to present proven productive alternatives to producers, who are at the end the decision-makers. It is important to know and to understand that the process just detailed above is proposed as an agronomic methodological approach; however, producer-decision-making processes by themselves also may and should be analyzed scientifically.

Environment

Because agricultural systems are site specific the environment where the system would be located must be understood as the conditions that cannot be easily modified. However, through technology, some environmental aspects can be modified to make the system more productive than if left as it was originally.

Climate

Weather refers to the atmospheric variables for a brief period of time. Climate, represents the atmospheric conditions for a longer period of time, and generally refers to the normal or mean course of the weather (Commonwealth of Australia 2004). Climate can now be expanded to include the future expectation of long term weather, in the order of weeks, months, or years ahead. The main climatic elements are precipitation, temperature, humidity, sunshine, and wind velocity; such phenomena as fog, frost, thunder, gale, cloudiness, grass minimum temperature, and soil temperature at various depths may also be included. Some areas do not have the technology to measure all of these factors, thus only temperature and precipitation are used to establish the climate type (Grissino-Mayer, 1999; Commonwealth of Australia 2004).

Agricultural activities are very sensitive to climate and weather conditions. An agricultural decision-maker can either be at the mercy of these natural factors or try to benefit from them. The only way to profit from natural factors is to include and understand them as well as possible. Agrometeorological information, in practice mainly climatological data, is essential in planning agricultural production. The following decisions should not be made without knowing climate conditions: land use and management, selecting plants and breeds of animals, and crop production practices such as irrigation, pest and disease control and crop-weather relationships (FMI-MDC, 2000).

Soil

From a simplistic point of view, the role of soil in a forage-crop-livestock system is to operate as the physical base of the productive activity. However, plant growth, probably the component with the greatest interaction with the soil, depends among other factors, on soil's characteristics and biological processes occurring in it. "Soil is a dynamic ecosystem that supports plant life by providing the essential requirements for growth, including nutrients, water, oxygen, and support (Pierzynski *et al*., 2000)."

The previous definition lacks descriptive aspects regarding soil itself. Soil can also be defined from an exclusively soil prospective, including plant growth only as a secondary aspect.

> Soil is a natural body comprised of solids (minerals and organic matter), liquid, and gases that occurs on the land surface, occupies space, and is characterized by one or both of the following: horizons, or layers, that are distinguishable from the initial material as a result of additions, losses, transfers, and transformations of energy and matter or the ability to support rooted plants in a natural environment (USDA-NRCS, 1999).

That definition led to the soil classification that ultimately helps to understand which plants, cultivated or not, can or cannot grow in a given soil type; soil classification also helps to determine some management strategies regarding the rest of the components.

Hydrology

Along with climate, hydrology is a basic component of the environment that ought to be taken into consideration when planning any agricultural operation from a sustainable point of view. Some of the actual concerns regarding sustainability in agriculture are related directly to the increasing scarcity of water and its also decreasing quality.

> Hydrology is the branch of geology that studies water on the earth, especially with relation to the effects of precipitation and evaporation upon the occurrence and character of water in streams, lakes, and on or below the land surface through the hydrologic cycle of: Precipitation, runoff, infiltration and storage; and evaporation. It is concerned with the

> physical and chemical reactions of water with the rest of the earth, and their relation to life (Novalynx, 1988; Branick, 1992).

The study and knowledge of hydrology of a particular region should help to develop adequate management of water resources. One of the most urgent aspects of water management in agriculture it is to start planning for the long term on the source and amount of water that can be devoted to irrigation without any detrimental effect, either on the amount available or its quality. In order to achieve that objective hydrology focuses, among others, on: 1) the study soil-water-plant relationships, 2) the prediction of rates and amounts of runoff, 3) the estimation of required spillway and reservoir capacities, and 4) available water supply.

Native vegetation

Although agriculture involves plants and their environment, the approach is different when native species are included. In general, native species have both negative and positive effects on agriculture; this idea as simplistic as it is, can become complicated when each one of these effects are studied in depth.

Native species have a negative connotation when considered as weeds and, therefore, are in open competition with crops. Weeds are aggressive, invasive, easily dispersed nuisance plants that interfere with management objectives/operations at a particular location (Dent and Allcott, 1996). Weeds are plants growing where they are not wanted, commonly in cultivated ground to the detriment of a crop and are not restricted to native species. However, under certain situations, plants regarded as weeds may not be totally undesirable; (Haddock, M. 1997b). As a positive view, some native species can be included as components of a productive system, taking advantage of their adaptation to the environment. From an ecological stand point native vegetation is the stabilized plant community on a particular site; it would exist in an area if growth had proceeded undisturbed for an extended period. The plant cover reproduces itself and it will not change as long as the environment remains the same (Birdsall and Florin, 1998).

Fauna

As in the case of native vegetation, wildlife also has different effects, depending on the objectives of the productive system.

> Wildlife is all non-domesticated and semi-domesticated mammals, birds, reptiles, and amphibians living in a natural environment, including both game species and non-game species, whether considered beneficial or otherwise. Land and water managed primarily for fish and wildlife. Wildlife may be a secondary use of land with cropland, rangeland, woodland, etc., as the primary use (Giles, 1998).

<u>Crop</u>

The crop component of this type of integrated systems should be well adapted to the environmental conditions of the site and producers should be familiar with its productive process. Because crop-forage-livestock systems may be a more sustainable alternative to crop or livestock systems already established, the idea of including the known crop as a component of the new system can give an advantage, at least on the first transitional years. Use of technology developed specifically for such a crop allows producers to take an activity with which they are not familiar at once. The final objective would be to find an alternative system that replaces the traditional one. In the long term, it is possible to eliminate the crop component because even as a component of a diversified system it is no longer affordable. The reality is that a crop system, standing by itself, is becoming obsolete; that is, productively inefficient and environmentally hazardous.

Forage

Forage, refers to “edible parts of plants, other than separated grain, that can provide feed for grazing animals, or that can be harvested for feeding” (FGTC, 1992). Forage within a crop-forage-livestock system should be:

1. Nutritiously adequate. The specie or species selected should be capable of producing forage of desirable quality.
2. Opportune. The forage species selected should allocate nutrients to livestock in the amount and at the time when they are needed.
3. Persistent. Forage production should occur over time in the long term. This characteristic does not refer in strict sense to the use of perennial species.

4. Productively complementary. It should provide a complementary source of profit for the system other than being converted to animal product; this can be done by either producing byproducts such as seed or hay, or functioning as a subsystem of two or more forage species where at least one of them would be annual in order to allow the use of the land for a secondary purpose, such as cropping. Forage production depends on the climate and soil type where the system is located and on the kind of livestock that will use it.

Livestock

Livestock in integrated crop-livestock systems is the component that, although sensitive to climate and environmental conditions is less dependent on these factors than on non-natural components such as market necessities and demands. After choosing the livestock specie that would fit in an integrated system in a given region, the forage component is proposed and then evaluated in terms of the environment. Thus, the livestock component can be regarded as “the” linkage component.

The rationale for including ruminants in systems that attempt to be sustainable is simple. Ruminants, through microbial fermentation, are capable of digesting cellulose, which gives the possibility of converting to human edible food, plant products that otherwise could not be used. Ruminant livestock production is consistent with sustainable agriculture practices in which forages are grown in arable land to minimize water use and soil erosion (Oltjen and Beckett, 1996).

Management strategies

More than a component by itself, management strategies synthesize all the information about environment, crop, forage, and livestock and the relationships among them. Management strategies determine success of the system. It is at this point when the decision-making process occurs and in case of any problems, corrective actions can be applied. Management decisions occur across components and in most of the cases, a decision taken regarding a set of components will affect the rest of them as well. It is important to remember that the success or failure of a system is as a whole; it is of no use to be successful just in some aspects, because if that occurs, in the long term the system would tend to disappear.

In general, to take advantage of the components involved in crop-forage-livestock systems, the use of forages by livestock should be done mainly through grazing, using few or no dietary complements and/or supplements. Grazing management is the manipulation of animal grazing in pursuit of a defined objective (FGTC, 1992). However, grazing is very complex and often requires a great amount of knowledge in order to succeed.

A grazing system is a defined, integrated combination of animal, plant, soil and other environmental components and the grazing methods by which the system is managed to achieve specific results or goals; understanding grazing methods as the defined procedure or technique of grazing management designed to achieve specific objectives (FGTC, 1992). Grazing systems and associated management practices have the ability to alter the nature and complexity of plant-animal interactions and they can substantially influence grazing patterns and utilization of a pasture (Gillen *et al*., 1990; Volesky *et al*., 1994).

To have an idea of the complexity of the grazing activity it should be noted that the Forage and Grazing Terminology Committee defines 2 types of grazing management and about 32 grazing methods; this committee also emphasizes that the definition of a grazing system should include information regarding, at least:

1. Land unit: number, size, kind, slope, erosion status and soil classification.
2. Livestock: number, kind, sex, size, and age.
3. Use and non-use periods of each land unit in the system.
4. Grazing method or methods.
5. Specie of forage.
6. Environment: geographic location and elevation, type of climate, mean annual and seasonal temperatures and precipitation.

Particular management strategies for plant defoliation and partitioning nutrients to animals are known as “grazing methods” and include rotational and continuous stocking (FGTC, 1992).

Mineral cycling

Mineral elements are key components of crop-livestock systems. They are essential for sustained plant and animal productivity.

For plants, the essentiality of mineral elements is defined by three main factors (Arnon and Stout, 1939):

1. The plant cannot complete its life cycle without the element;
2. The function of the specific element cannot be substituted by another substance; and,
3. The element is directly involved in a metabolic function.

According to the prior criteria, 17 mineral elements have been determined to be essential for plants, and are classified as follows:

1. Organic elements: Carbon (C), hydrogen (H), and oxygen (O). They are obtained from CO_2 and water;
2. Macro-nutrients: Nitrogen (N) although it is not a mineral it is regarded as an essential element, phosphorus (P), potassium (K) Calcium (Ca), magnesium (Mg), and sulfur (S). They are, in the majority of the cases, supplied as fertilizers; and,

3. Micro-nutrients: Boron (B), chlorine (Cl), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni), and zinc (Zn).

(Marschner, 1986; Baker *et al*., 1997).

For ruminants, the concept of essentiality of mineral elements is similar to that of plants, because of their participation on the completion of the life cycle (bone formation and/or constituents of animal tissue, growth and reproduction) and metabolic functions. There are at least 17 essential mineral elements for beef cattle (NRC, 1996):

1. Macro-minerals: Elements required in large amounts; they include Ca, Mg, P, K, sodium (Na), Cl and S.
2. Micro-minerals: Also called trace elements, are required in small amounts; they include chromium (Cr), cobalt (Co), Cu, iodine (I), Fe, Mn, Mo, nickel (Ni), selenium (Se), and Zn.

Mineral cycling is a process always in motion occurring independently of the activities on the field and is affected by the same factors influencing the productive system, but at the same time, is also affected by the productive system itself.

Table 1.1. Essential elements required by plants and beef cattle.

Element	Plant†		Beef cattle‡	
	Ion forms absorbed	Amount, μmol g^{-1}DM	Amount required, mg kg^{-1}	Amount tolerable, mg kg^{-1}
N	NH_4^+, NO_3^-	1000.0	-	-
P	$H_2PO_4^-$, HPO_4^{2-}, PO_4^{3-}	60.0	19.0 g day, 2.3g kg DM	-
K	K^+	250.0	6000	-
Ca	Ca^{2+}	125.0	8.0 g day, 4.4 g/kg	-
Mg	Mg^{2+}	80.0	1000.0	4000.0
Na	-	-	60.0-80.0	-
B	H_3BO_3	2.0	-	-
Cl	Cl^-	3.0	-	-
Cr	-	-	-	1000.0
Co	-	-	0.10	10.0
Cu	Cu^{2+}	0.10	10.0	100.0
Fe	Fe^{2+}	2.0	50.0	1000.0
I	-	-	0.50	50.0
Mn	Mn^{2+}	1.0	20.0	1000.0
Mo	MoO_4^{2-}	0.001	-	5.0
Ni	Ni^{2+}	0.001	-	50.0
Se	-	-	0.10	2.0
S	SO_4^{2-}	30	1500.0	4000.0
Zn	Zn^{2+}, $ZnOH^+$, $ZnCl^+$	0.3	30.0	500.0

† Marschner, 1995; Baker *et al*., 1997
‡ NRC, 1986

Sources of mineral elements in any specific system vary whether they are already present in the soil or they enter the system as applied fertilizer, through atmospheric deposition of gaseous sources, or deposition of livestock wastes that contain elements derived from supplemental feeds obtained outside the system. Regarding the elements already present in the soil, some of them must undergo some type of transformation (solubilization, weathering from clay mineral layers, mineralization of organic compounds) before they can be readily available for plant uptake (Joost, 1996). Losses of mineral elements include leaching below the root zone (N and S); runoff when elements are applied on the soil surface as fertilizer, manure, or plant residue (P). These elements can become deficient in plants and animals. Besides, both pathways are environmentally hazardous because they have the potential of polluting water sources, below and above ground (Joost, 1996). Another loss of mineral elements is the removal of products of either plant or animal origin; however, the impact of this pathway in the overall loss of mineral depends on the nutrient content of the product removed.

Hay or silage systems can produce large losses as well as cattle operations where harvested forage is fed at a different site from where forage is produced, thus, manure is not returned to the site of forage production, so minerals are no longer cycled within the system. Grazing systems are more efficient in avoiding mineral losses because animals remove only a portion of the plant and much of what they ingest is returned to the same site in the form of manure (Joost, 1996; Briske and Heitschmidt 1991; Entz *et al.*, 2002).

Economics

Economics in agriculture is considered as the ultimate indicator of the success or feasibility of any productive or agricultural activity and, in the majority of the cases profitability is the most important objective to be achieved. Crop production occurs in an environment that is always changing. With every growing season, producers must attend to numerous factors that influence their management decisions. Some factors are within the control of producers; many are not. The weather, market conditions, input prices, government programs, and new technology and information represent broad categories of externalities that producers must deal with on a continual basis. This is a daunting challenge, especially when one considers that producers' decisions are carried out in a competitive financial environment where one wrong decision could mean financial hardship and potentially the end to a way of life (Tanaka *et al*., 2002).

Components of integrated crop-livestock systems in the Texas High Plains

> "Only the truly imaginative saw prosperity on the empty arid central grasslands."
> Christopher Oglesby.

The Texas High Plains region is located at the northern and western side of Texas from the Panhandle to the Pecos River. Physiographically it is a quadrangular, mesa-like area with an average elevation of 1,000 m that rises perceptibly by sharp escarpments above the adjacent lowlands. It is characterized by a constructional topography formed on thick deposits of wind-blown materials. The textures of these materials vary from east to west, the finest textures occurring in the eastward zone, the coarser or sandy textures in the westward zone, with a transitional zone in between. The eastern boundary is a westward-retreating escarpment capped by hard caliche.

Although topographically the High Plains region is upland and the surface consists of a veneer of deposits geologically recent, it overlies the Permian basin which is a vast structural feature lying eastward of the Rocky Mountains below which are still older beds of the Early Paleozoic, which in turn rest on the pre-Cambrian basement. The Permian basin consists of two sub-basins, the western Delaware basin and the eastern Midland basin, together with the West Texas, or Central Basin

Platform in between. These sub-surface features are important for the oilfields of West Texas and southeastern New Mexico. The area possesses large deposits of minerals chemically precipitated, such as salt, potash, and gypsum, laid down in the different phases of the desiccating seas of Permian time. In the southern part of the High Plains, brines in shallow lakes and in shallow subsurface accumulations supply the raw materials for the production of salt cake (Johnson, 2002; Wermund, 1996).

Environment

Agriculturally, the middle sector of the Great Plains is predominantly the hard winter wheat region of the United States. This region extends southward well into the High Plains, occupying most of the Texas Panhandle. South of the Plainview area, cotton and grain sorghums are the dominant crops. Formerly the High Plains region was entirely a grazing country. Rainfall decreases toward the west and becomes more irregular in occurrence and distribution. As a consequence, the livestock range industry remains important throughout the western portions of the High Plains. The southern portion of the High Plains, particularly south of Lubbock, contains areas of somewhat broken topography; such lands are mostly devoted to grazing. The areas of deep sands are almost exclusively grazing lands (Johnson, 2002).

On the High Plains, widespread small, intermittent streams dominate the drainage. Headwaters of major rivers deeply notch the Caprock, as exemplified by Palo Duro Canyon and Caprock Canyons State Parks. The Canadian River cuts across the province, creating the Canadian Breaks and separating the Central High Plains from the Southern High Plains. Pecos River drainage erodes the west-facing escarpment of the Southern High Plains, which terminates against the Edwards Plateau on the south. Numerous playa lakes scatter randomly over the treeless plains. Extensive stream-laid sand and gravel deposits, which contain the Ogallala aquifer, underlie the plains (Wermund, 1996).

Climate

The Texas High Plains are located within the Dry Mid-latitude climate zone; according to Köppen’s classification (Leemans Cramer, 1991) this type of climate belongs to the BS or dry semiarid (steppe) type. BS climates are a grassland climate that covers 14% of the Earth's land surface. It can be found between the desert climate (BW) and more humid climates of the A, C, and D groups (Pidwirny, 1999). These climates extend from 20 - 35° North and South of the equator and in large continental regions of the mid-latitudes; they exist in the interior regions of Western North America (Great Basin, Columbia Plateau, Great Plains); and Eurasian interior, from steppes of eastern Europe to the Gobi Desert and North China (Pidwirny, 1999; Grissino-Mayer, 1999; Strahler and Strahler, 1984). BS climates are frequently located in the lee side of high mountains thus, dominated by rain shadow effects. Moist ocean air masses are blocked by mountain ranges to the west and south.

These mountain ranges also trap polar air in winter, making them very cold (Strahler and Strahler, 1984; Pidwirny, 1999; Grissino-Mayer, 1999; Ritter, 2003).

The BS climate is a semi-arid environment. It can be defined as one where the annual potential evapotranspiration is more than half but less than the total annual precipitation (Pidwirny, 1999). Potential evapotranspiration is a measure of the demand for water on account of plant transpiration and surface evaporation. In the tropical steppe, much evaporation and plant transpiration would take place if water were available. Meager amounts of precipitation during the relatively long summer droughts stress plants that require water during periods of high temperature; however, during the wet portions of the year, ample precipitation occurs to meet the needs of the natural vegetation (Ritter, 2003). From May to October precipitation is more than half but less than potential evaporation of steppe/grassland/bunch grasses (Kimmel, 2000; USDA-FS, 2004). Annual evaporation is 1,800 to 2,000 mm (USDA-FS, 2004). The growing season lasts 130 to 220 days, increasing from north to south and from west to east (USDA, 1981; USDA-FS, 2004).

Temperature. In BS climates continental effects are strong, resulting in a large annual temperature range (Grissino-Mayer, 1999). Daily temperature ranges are nearly similar to, or larger than, the annual range of temperature (Ritter, 2003). Summers are long and warm to hot, and winters are short and mild. During this season there are few clouds to keep heat from escaping into the upper atmosphere. These cloudless conditions also exist in the summer season which allows much solar radiation in to warm the surface (Strahler and Strahler, 1984; USDA-FS, 2004).

In general it can be said that in the BS climates seasons are distinguished on the basis of it being warm and excessively warm. Average annual temperature in the BS climate is approximately 20°C, with a variation from 10 °C to above 30 °C; however, there are disagreements about this average even within the same agency from 16 to 21 °C (USDA-FS, 2004); to 13 to 17 °C (USDA, 1981); while some other authors point to 24 °C (Strahler and Strahler, 1984). This disagreement can be based on the fact of the wide daily temperature range.

Precipitation. BS climate is a transitional type between truly wet and truly dry climates. The seasonality of precipitation is similar to that of the closest humid climate (Ritter, 2003). Average annual precipitation is around 375 to 550 mm, but fluctuates widely from year to year. The low precipitation in winter is mainly snow (USDA, 1981). This type of climate tends to go in cycles where there may be 10 years or more of good rains followed by as many years of drought (Strahler and Strahler, 1984; USDA-FS, 2004). The main difference between steppes and deserts are determined by the mean annual temperatures and precipitation (Strahler and Strahler, 1984). There is not enough precipitation for trees to grow except by rivers. The plants have adapted to these drought conditions by being small and growing extensive root systems. Animals have adapted by burrowing into the ground to stay cool or warm, and to find protection on the open plains of the steppe (Strahler and Strahler, 1984).

Soil

Most of the Texas High Plains lies in a belt of country extending from the lower Rio Grande and the southern portion of the Texas Gulf coast northward across the middle and northern Great Plains well into the plains of western Canada. The Texas portion makes up most of the southern third of this soils zone as it occurs in the United States (Johnson, 2002).

Soils in this region are formed from windblown sands and silts that form rich soils and caliche. They are deep, fine to coarse textured, well drained, and have limited soil moisture for use by vegetation during parts of the growing season. The different soil orders are well correlated with the different plant communities. The mesquite (*Prosopis glandulosa*)-live oak (*Quercus agrifolia*) savanna is the only Entisol area in the region. Soils of the mesquite-buffalo grass (*Buchloe dactyloides*) and juniper (*Juniper* spp.)-oak savannas are almost entirely Mollisols with an ustic moisture regime: Paleustolls on ridges and steeper slopes (Pullman, Olton, Acuff, Sherm, Gruver, Texline, Dumas, Mansker, Conlen, Sunray, and Estacado series) are dominant on ridges and on the more sloping parts. Argiustolls (Richfield series), Calciustolls (Portales and Dioxice series), and Haplustolls can be found on young valley floors and flood plains of the streams (Ulysses, Bippus, Humbarger, and Spur series); Alfisols with an ustic moisture regime: Paleustalfs (Amarillo, Dallam, Rickmore, and Spurlock series), and Haplustalfs are located on uplands within the area corresponding to the boundaries of the mesquite-oak savanna (Dalhart series). In the mesquite-acacia (*Acacia spp.*) savanna, Mollisols, Alfisols, and Vertisols occur.

Other characteristics of the soils are a mesic or thermic temperature regime, and mixed or carbonatic mineralogy (USDA-FS, 2004). Pellusterts are in clayey playa-lake basins (Randall and Ness series). Shallow Calciorthids (Potter series), Paleorthids (Pastura series), and Entisols: Torriorthents are on steep slopes in breaks (Travessilla series; USDA-FS, 2004). Alfisols with an ustic moisture regime: Paleustalfs (Patricia, Springer, and Brownfield series), Aridiosols: Haplargids (Triomas, Faskin, and Jalmar series), Entisols: Ustipsamments (Tivoli series), and Torripsamments (Penwell series) are deep sandy soils in the southwest. Loamy, shallow to moderately deep soils in the southwest are Mollisols: Calciustolls (Kimbrough series), Paleustolls (Lea, Slaughter, and Stegall series), Alfisols: Paleustalfs (Arvana series), Paleorthids (Blakeney and Conger series), and Paleargids (Douro and Sharvana series) (USDA, 1981).

Hydrology

In the Texas High Plains the moderately low and erratic precipitation is the source of water for dry-farmed crops and for range. Irrigation water is obtained from wells, but in the central and southern parts withdrawals exceed recharge, and the water table is gradually declining. Some areas formerly irrigated are now dry-farmed (USDA, 1981).

The main source of irrigation water in the Texas High Plains is the Ogallala Aquifer, which underlies approximately 585,000 km^2 in the Great Plains region. In the Texas High Plains the aquifer covers around 93,808 km2 square miles and consists predominantly of the Ogallala Formation of late Tertiary age with locally unconsolidated deposits of Quaternary age included. In some places, the aquifer is in hydraulic connection with permeable parts of the underlying bedrock, which ranges in age from Permian to Cretaceous (Jensen, 2004; Glantz, 1989).

The High Plains area represents 65% of the total irrigated area in the U.S. with 2,050,154 ha per yr (Texas Agricultural Statistics Service, 2004). The aquifer contains roughly 98 billion ha-cm of water of which 12,510 million ha-cm are in Texas. Texas High Plains totals more than 180 million ha-cm of water for irrigation but is predicted to decline to 150 million ha-cm by 2060 (Jensen, 2004).

Flora

The vegetation of the Texas High Plains is characterized by arid grasslands of short-grass communities composed of bunch grasses in which shrubs and low trees grow singly or in groups the northern portion of this area being one of the most distinctive short grass regions of the United States. Short grasses such as blue grama [*Bouteloua gracilis* (Wild. ex Kunth)] and buffalo grass [*Buchloe dactyloides* (Nutt.)] are typical, mid-grasses such as sideoats grama [*Bouteloua curtipendula* (Michx.) Torr.] grow on the more open soils and breaks; tall grasses such as sand bluestem [*Andropogon hallii* (Hack.)], little bluestem [*Schizachyrium scoparium* (Michx.) Nash.], and indiangrass [*Sorghastrum nutans* (L.) Nash.] grow mixed with shin oak [*Quercus havardii* (Rydb.)] and sand sagebrush [*Artemisia filifolia* (Torr.)] on the sandy soils. A wide range of perennial forbs also grow on the sandier soils and are characterized by dotted gayfeather [*Liatris punctata* (Hook.)], pitcher sage [*Salvia spp*. (L.)], sage wort [*Artemisia annua* (L.)], bush sunflower [*Simsia calva* (Engelm. & Gray) Gray.], yucca [*Yucca spp.* (L.)] and daleas [*Dalea spp*. (L.)]. However, on the south area, mesquite [*Prosopis spp.* (L.)] grows in open stands among the grasses. An important fact about the region is that about 90% of this area has been converted to cropland or pasture (Johnson, 2002; USDA-FS, 2004).

Fauna

Texas High Plains wildlife includes large to medium size herbivores and carnivores such as pronghorn [*Antilocarpa americana* (L.)], coyote [*Canis latrans* (L.)], swift fox [*Vulpes velox* (L.)], ringtail [*Bassariscus astutus* (L.)], and ocelot [*Leopardus pardalis* (L.)]; Bison [*Bison bison* (L.)] are historically associated with this area. Smaller herbivores include desert shrew [*Notiosorex crawfordi* (L.)], desert cottontail [*Sylvilagus auduboni* (L.)], black-tailed prairie dog [*Cynomys ludovicianus* (L.)], yellow-faced pocket gopher [*Cratogeomys castanops* (L.)], plains pocket mouse [*Perognathus flavescens* (L.)], silky pocket mouse [*Perognathus flavus* (L.)], hispid pocket mouse [*Chaetodipus hispidus* (L.)], and white-throated wood rat [*Neotoma albigula* (L.)]. Birds include species that occur over a wide area, such as roadrunner [*Geococcyx californianus* (L.)], house finch [*Carpodacus mexicanus* (L.)], yellow warbler [*Dendroica petechia* (L.)], willow flycatcher [*Empidonax traillii extimus* (L.)], cedar waxwing [*Bombycilla cedrorum* (L.)], western kingbird [*Tyrannus verticalis* (L.)], and golden eagle [*Aquila chrysaetos* (L.)]; the lesser prairie chicken [*Tympanuchus cupido* (L.)], found here, is restricted to the more arid grasslands. Amphibians found in this area include plains spadefoot toad [*Spea bombifrons* (L.)], Couche's spadefoot toad [*Scaphiopus couchii* (L.)], western spadefoot toad [*Spea hammondii* (L.)], plains leopard frog [*Rana blairi* (L.)], Great Plains toad [*Bufo cognatus* (L.)], green toad [*Bufo debilis* (L.)], red spotted toad [*Bufo punctatus* (L.)], spotted chorus frog [*Pseudacris clarkii* (L.)], and yellow-mud turtle [*Kinosternon flavescens* (L.)], Reptiles include species such as Texas horned lizard [*Phrynosoma* *cornutum* (L.)], round-tailed horned lizard [*Phrynosoma modestum* (L.)], Great Plains skink [*Eumeces obsoletus* (L.)], Texas blind snake [*Leptotyphlops dulcis* (L.)], and plains black-headed snake [*Tantilla nigriceps* (L.)] (USDA-FS, 2004).

<u>Introduced vegetation and livestock</u>

Cotton and grain sorghum are the primary introduced crops to the Texas High Plains. In fact, Texas is the largest cotton producer in the U.S. producing around 25% of the total cotton in the country. Cotton is grown in about 2.5 million ha and generates $1.6 billion for farmers and around $5.2 billion for the state (TAMU, 2005). The Texas High Plains produces 64% of the total state's cotton crop with about 50% of it in irrigated lands (NCSU, 2005; Texas Agricultural Statistics Service, 2002). Grain sorghum is grown to a lesser extent often as a rescue crop when the cotton crop is damaged by hail or other environmental factors. Wheat and corn are other crops grown in the region with corn producing area declining as water for irrigation becomes scarcer.

Primary introduced cool-season forages in the region for grazing are the small grains, and especially wheat, rye, oats [*Avena sativa* (L.)], barley [*Hordeum vulgare* (L.)] and triticale are well adapted. Few cool-season perennial grasses are grown but tall and intermediate wheatgrass [*Thinopyrum intermedium* (Host.) Barkworth & D.R. Dewey] and tall fescue [*Festuca arundinacea* Schreb.] have been used occasionally. Alfalfa [*Medicago sativa*] is well adapted but low water availability limits its use.

Introduced forages include lovegrass [*Eragrostis curvula* (Schrad.) Nees.], bermudagrass [*Cynodon dactylon* (L.) Pers.], and the old world bluestems (*Bothriochloa spp*.) as among the most successfully introduced grasses in the Texas South Plains.

WW-B. Dahl old world bluestem as forage

WW-B. Dahl old world bluestem (registration number CV-50 PI 300857) was released jointly by the USDA-ARS, USDA-SCS, Texas Tech University, and the Texas Agricultural Experiment Station in March 1994 (Dewald *et al*., 1995). Seeds of this specie were first collected in India in 1960 and plants were subject to experimentation at several research stations in Oklahoma as well as in Georgia. It was at the Southern Plains Range Research station in Woodward, OK where the final experiments prior to its liberation were conducted under the denomination 'WW-875' (Dewald *et al*., 1995). References to this specie, however, can be found in the literature under several synonyms, the most recurrent being: *Bothriochloa intermedia* [(R. Br.), A. Camus]; *B. caucasica* [(Trin.), C.E. Hubbard]; *Andropogon intermedius* (R. Br.); A. *bladhii* (Retz.); *Dichanthium bladhii* [(Retz.), Clayton] (Institute of Pacific Islands Forestry, 2003; Haddock, 1997). Throughout time, botanical classification has changed. As a result, the following are *B. bladhii* synonyms that are not longer in use: *Andropogon bladhii* ([Retz. 1781) *A. intermedius* (R. Brown, 1810); *A. glaber* (Roxburgh, 1820); *A. punctatus* (Roxburgh, 1820); *A. annulatus* [Forsskal, var.

bladhii (Retzius) Hackel, 1889]; *A. intermedius* var. *genuinus* (R. Brown, Hackel, 1889); *A. intermedius* subvar. *glaber* [R. Brown, (Roxburgh) Hackel, 1889]; *A. intermedius* var. *punctatus* [R. Brown, (Roxburgh) Hackel, 1889] *A. intermedius* subvar *perfossus* (R. Brown, Hackel, 1889); *A. pertusus* var. *vegetior* [(Linnaeus) Willdenow, Hackel, 1889]; *Amphilophis intermedia* [(R. Brown) Stapf. 1916]; *A. intermedius* var. *acidula* [R. Brown, Stapf, 1916); *Amphilophis glabra* [(Roxburgh) Stapf 1917]; *A. insculpta* var. *vegetior* [(A. Richard) Stapf, (Hackel) Stapf 1917]; *Bothriochloa glabra* [(Roxburgh) A. Camus, 1931]; *B. intermedia* [(R. Brown) *A. Camus*, 1931]; *B. insculpta* var. *vegetior* [(A. Richard) A. Camus, (Hackel) C. E. Hubbard, 1934]; *B. intermedia* var. *acidula* [(R. Brown) A. Camus, (Stapf) C. E. Hubbard, 1934]; *Dichanthium ischaemum* subvar *intermedium* [(Linnaeus) Roberty, (R. Brown) Roberty, 1960]; *D. bladhii* [(Retz.), Clayton, 1977] (Wunderlin and Hansen, 2003).

In addition to the problem of synonyms, *B. bladhii* has also several common names, which add to the confusion when this cultivar is subjected to research. Some of those names are: Australian Beard grass; Australian bluestem; Forest blue grass (*B. bladhii* var*. bladhii*, Australia); Swann (*B. bladhii* var. *glabra*, Australia); Lautoka grass (Fiji); Thamboni grass (Fiji); Caucasian bluestem; Desum (Palau) (Institute of Pacific Islands Forestry; Haddock, 1997a; Wunderlin and Hansen, 2003; Graham and Pegler, 2004).

In the present document the common and scientific names that will be used are: WW-B. Dahl old world bluestem [WW-B. Dahl; *Bothriochloa bladhii* (Retz.), S.T.

Blake, 1969]. Being the most recently liberated cultivar among the old world bluestems, information regarding WW-B. Dahl forage value is limited. However, information on the other species in the genus *bothriochloa* does exist.

In field tests at the Texas Tech Experimental Ranch, over 3 yr, *B. Dahl* consistently produced more forage, 6,580 kg ha^{-1} than other old world bluestems (*Bothriochloa spp.*) 2,867 kg ha^{-1} under non-irrigated conditions (Dewald *et al*., 1995). These evaluations encompassed relatively dry, wet and average years. One of the major advantages of WW-B. Dahl is its relatively high quality forage during July, August and September. When tested with standard laboratory techniques, WW-B. Dahl was slightly higher in crude protein (CP) than the other old world bluestems (Dewald *et al*., 1995; NRCS, 1998; Philipp, 2004).

At Lometa, Texas, observations of cattle grazing WW-B. Dahl showed that palatability of this grass was similar to that of WW-Iron Master, WW-Spar [both *B. ischaemum* (Keng.)] and Caucasian (*B. caucasica* C.E. Hubb). When stocker steers were on free choice animal acceptance trials; cattle would seldom leave the planted field of WW-B. Dahl to graze the adjacent pastures (Dewald *et al*., 1995).

Although grazing systems success depends not only on animal performance but also on other factors such as the impact of the grazing practice on soil, plant, and pasture characteristics, a great deal of research using Old World Bluestems has been done emphasizing their use as a forage and little has been reported regarding their role as a component of an integral system. In general, WW-B. Dahl has been suggested to enhance any current forage program and lengthen the grazing season.

Also, well managed, all Old World Bluestem will maintain or improve soil condition, provide erosion protection, improve water quality, and increase water retention on the farm (Dewald *et al*., 1995). Old World Bluestem (*Bothriochloa ischaemum* L.) has been reported as the major grass being planted for improved pastures in western Oklahoma and adjacent areas in Texas (Berg *et al*., 1996).

In central Texas a study carried on for 3 yr in dry-land condition showed that WW-B. Dahl had the highest biomass yields when compared with buffelgrass, Irene tufted digitgrass,(*Digitaria eriantha* Stued.), Carostan flaccidgrass (*Pennisetum flaccidum* Greisb.), 'Palar' Wilman lovegrass (*Eragrostis superba* Pevr.), P.I. 269961 Oriental pennisetum (*Pennisetum orientale* Rich.), 'Ermelo' weeping lovegrass, [(*Eragrostis curvula* Schrad.) Nees var. *curvula* Nees)], and 'Selection-75' kleingrass (*Panicum coloratum* L; Sanderson *et al*., 1999).

In New Deal TX, WW-B. Dahl was compared with 'Ermelo' weeping lovegrass, *B. caucasica* and three cultivars of *B. Ischaemum* regarding their grazing potential (Niemann, unpublished data, Texas tech University). Results of this study showed that WW-B. Dahl had the highest yields of all grasses tested, although the length of the grazing season was not different. Regarding nutritive value, WW-B. Dahl had the highest content of CP in June. In August, WW-B. Dahl had the lowest NDF percentage, although it did not differ from the other *Bothriochloa* species; the lowest lignin content; and the highest TNC proportion. WW-B. Dahl, also produced the highest gains per ha and per animal. All these results indicate the high potential of WW-B. Dahl to be used as a grazing forage in the Texas High Plains (Niemann, 2001; unpublished data, Texas Tech University).

Also in New Deal, TX, another study was carried on in which WW-B. Dahl was compared with *B. ischaemum* and *B. caucasica* under several irrigation treatments (Philipp, 2004). In two of the three yr of the study, WW-B. Dahl had higher yields than *B. ischaemum* although they were similar to the biomass yields of *B. caucasica*. During the last yr of the experiment, all three *Bothriochloa* species had similar yields. In average, WW-B. Dahl had biomass yields of 15.2 Mg ha^{-1} (Philipp, 2004).

Small grains as forage

Annual forage species such as wheat (*Triticum aestivum* L.) and rye (*Secale cereale* L.) are the primary cool-season forages grazed by growing beef cattle in the southern Great Plains region of the United States (Redmon *et al*., 1995).

At the New Mexico State University (NMSU) Agricultural Science Center at Tucumari, N.M. steers grazed either winter wheat or native rangeland species {blue grama [*Bouteloua gracilis* (H.B.K.) Lag. Ex Steud.], sideoats grama, and sand dropseed [*Sporobolus cryptundrus* porr.) A. Grey] and yellow bluestem, threeawns (*Aristida spp*.), lovegrass (*Eragrostis spp*.), vine mesquite (*Panicum obtusum* H.B.K.), and silver bluestem [*Bothriochloa saccharoides* (SW. Rydb.]} as sub-dominant grasses. During the winter, winter wheat pastures were higher in CP and available crude protein (ACP) and lower in acid detergent insoluble nitrogen (ADIN) than rangeland pastures. Percentage NDF and ADF were similar between pasture types, but those of wheat tended to have lower values. Percentage acid detergent lignin (ADL) was higher in rangeland pastures compared with wheat. Winter wheat had greater in vitro organic matter digestibility when compared to rangeland pastures. No differences were observed in intake when expressed as percentage of body weight or total intake on either organic matter basis or dry matter basis. Steers grazing winter wheat had greater gain than those grazing rangeland pastures (Kloppenburg *et al*., 1995).

General research objective

The preceding review of literature was compiled with the intention of constructing a theoretical framework on which to base the study of integrated crop-livestock systems; however, the review of literature also incorporated the fact that at the beginning of this research there was an integrated crop-forage system already established, thus, specific information regarding the Texas High Plains environment, WW-B. Dahl, rye, and wheat was summarized.

The analysis of the information in the second part of the literature review demonstrated the need for information on: 1) the value of WW-B. Dahl as forage and 2) the cycling of minerals in integrated productive system; this analysis also pointed out the lack of economic evaluation in the cases when agronomic information was available.

Therefore, as a result of the previous conclusions, the general objective of this research was to collect agronomic and economic information of a functioning integrated crop-livestock system in order to evaluate its productive ability.

In order to accomplish the general objective several specific objectives were proposed:

1. Compare the effect of a cotton monoculture system and an integrated crop-livestock system on soil mineral concentration and compaction.
2. Compare the effect of grazing vs. no grazing activity on extractable soil minerals and soil compaction in an integrated crop-livestock system.
3. Compare the effect of three grazing periods on extractable soil minerals and soil compaction in a WW-B. Dahl perennial pasture.
4. Compare the effect of different defoliation strategies on WW-B. Dahl biomass yield and accumulation, botanical composition, forage quality, and mineral concentration.
5. Compare the economic profitability of a cotton monoculture and an integrated crop-livestock system.

CHAPTER II

EXTRACTABLE SOIL MINERALS AND SOIL COMPACTION IN AN INTEGRATED CROP-LIVESTOCK SYSTEM IN THE TEXAS HIGH PLAINS

Abstract

An understanding of mineral cycles is imperative to define nutrient management strategies for both plants and animals in integrated crop-livestock systems and crop monocultures but information on these cycles is often limited. In 1997, two systems were established in the Texas High Plains to compare a cotton (*Gossypium hirsutum* L.) monoculture system using management practices recommended by the Texas Cooperative Extension Service and an integrated crop-livestock system for production of cotton and feedlot ready stocker steers that included WW-B. Dahl [*Bothriochloa bladhii* (Retz.), S.T. Blake]. as a perennial forage and rye (*Secale cereale* L.) and wheat (*Triticum aestivum* L.) in alternate yearly rotation with cotton for grazing by steers. Averaged over the 6 yr of the project, steers grazed either 0 (non-grazed) or 49, 40, 23, and 60 d in dormant WW-B. Dahl, rye, wheat, and spring growth WW-B. Dahl, respectively. In May 2001 a short-term grazing interval was imposed in the WW-B. Dahl component of the integrated system, thus, averaged over 3 yr, steers grazed 0, 38, and 60 d. Soil samples were taken at depth intervals of 0-5, 5-10, and then at 10-cm increments to 60 cm in May

2001 and in December 2003 in the cotton monoculture, rye, wheat, and WW-B. Dahl paddocks including non-grazed areas and areas grazed at different lengths. Compaction readings were taken in the same areas where soil samples were collected in February, June, July, and in November following harvest of WW-B. Dahl seed of 2003. Additionally soil compaction was recorded among grazing intervals of WW-B. Dahl in June and July of 2002 and in February, June, July, and November following the harvest of WW-B. Dahl seed of 2003. Nitrogen as nitrate was extracted at all seven depths and P, K, Ca, Mg, Cu, Fe, Mn and Zn were extracted at the first four depth increments in both the cotton monoculture and the grazed areas of the integrated systems. Effects of grazing vs. no-grazing on minerals within the top 5 cm of soil was investigated. Each system, integrated system component, depth and grazing treatment was replicated three times in a randomized block design with a split-split-plot arrangement of the depth interval and a split-plot arrangement of the system, integrated system component, and grazing treatments. All minerals were within the normal ranges required for plant growth. Nitrogen and P fertilizer applications were made. Although some differences between cotton monoculture and the integrated system occurred, there was little evidence of system effects and little evidence of change over time. Zinc was higher in non-grazed than grazed soils, regardless of forage species. Grazing generally increased soil compaction but effects disappeared within non-grazed periods. Research is needed to investigate further changes over a longer time period.

Introduction

The main role of soil in agriculture is to provide the base for plant growth as it provides physical support, water, and nutrients (Schulze, 1989). However, when crop-livestock systems are the objective, interaction of soil with livestock is also important and sometimes overlooked. Mineral concentration in soil is one of the critical aspects for production in crop-livestock systems, because of its susceptibility to be altered, and because it is the primary source of mineral nutrition for both the plant and the grazing animal. Soil is no longer just a provider of resources for plant growth but becomes also a receptor; thus, this dynamic cycle becomes important.

Minerals constitute about 50% of the volume of most soils (Schulze, 1989). Although there is no linear relation between mineral status in soil, plants, and livestock due to several factors affecting availability and uptake of minerals, mineral concentration in soil can be signaled as the starting point of the cycle, due to the fact that individual mineral cycles often begin there. An understanding of these cycles is imperative to define nutrient management strategies for both plant and animal in integrated crop-livestock systems and crop monocultures but information on these cycles is often limited.

Mineral cycling is one of the processes regulated in part by soil, through its role as provider-receptor in crop-livestock systems; however, this does not preclude the possibility of having additions or losses of minerals at other points in the process. Mineral cycling is impacted differently in crop monocultures, crop rotations, use of cover crops, and when livestock become a part of the system as mineral imports and exports differ. Mineral losses in crop-livestock systems are often lower than losses in traditional cropping systems due to recycling through the animal whereas crop harvest exports large quantities of minerals.

In May 2001, three experiments were established to investigate effects on extractable soil minerals and soil compaction in a cotton monoculture and a crop-livestock integrated system. Effects of grazing vs. no grazing by steers in the integrated system, and three grazing intervals in WW-B. Dahl were also investigated. Experiments were conducted during three growing seasons until November 2003.

Materials and Methods

In 1997, two systems were established to compare a cotton monoculture system using management practices recommended by the Texas Cooperative Extension Service and an integrated crop-livestock system for production of cotton and feedlot ready stocker steers that included WW-B. Dahl [*Bothriochloa bladhii* (Retz.), S.T. Blake]. as a perennial forage and rye (*Secale cereale* L.) and wheat (*Triticum aestivum* L.) in alternate yearly rotation with cotton for grazing by steers (Allen *et al*, 2005). Both systems were established in the Northeast Lubbock County Plant Stress Field Laboratory of the Department of Plant and Soils Science of Texas Tech University. The soil type at the research site was Pullman clay loam (Fine, mixed, superactive, thermic Torrertic Paleustoll). The Pullman series consists of deep, well-drained, slowly permeable soils that formed in calcareous, loamy and clayey eolian sediments in the Blackwater Draw Formation of Pleistocene age. These soils are on nearly level to very gently sloping plains (0 to 3%). This soil has an ustic moisture regime bordering on aridic. The moisture control section is dry in some or all parts for more than 180 but less than 205 d, cumulative, in normal years. July through August and December through February are the driest months. They are intermittently moist in September through November and March through June. Average annual soil temperature ranges from 13.3 to 16 °C. Depth to secondary carbonates varies from 50.8 to 72 cm with a calcic horizon located from 72 to 144 cm. Thickness of the mollic epipedon is of 30.5 to 72 cm. These soils are mainly cultivated with irrigated and dryland cotton, corn, grain sorghum, and winter wheat. They are located on the Southern High Plains of Texas and eastern New Mexico (within an elevation from 900 to 1,200 m.

The climate at the research site was classified as a BSk (cool dry steppe climate with mild winters) with an average annual temperature of 15.8 °C with a maximum of 26.6 °C in July and a minimum of 3.8 °C in January (Leemans and Cramer, 1991). Maximum and minimum average temperatures over the same period of time were 23.3 and 8.3 °C respectively; the highest maximum average temperature being 33.9 °C in July and the lowest minimum average -3.1 °C in January. These averages fall out of the boundaries reported in the literature for BS climates. Average frost-free period of 203 d. Total average precipitation is 462 mm and occurs from April through October with a peak of 78 mm on July; the average driest month being January with 15 mm (Fig 2.1).

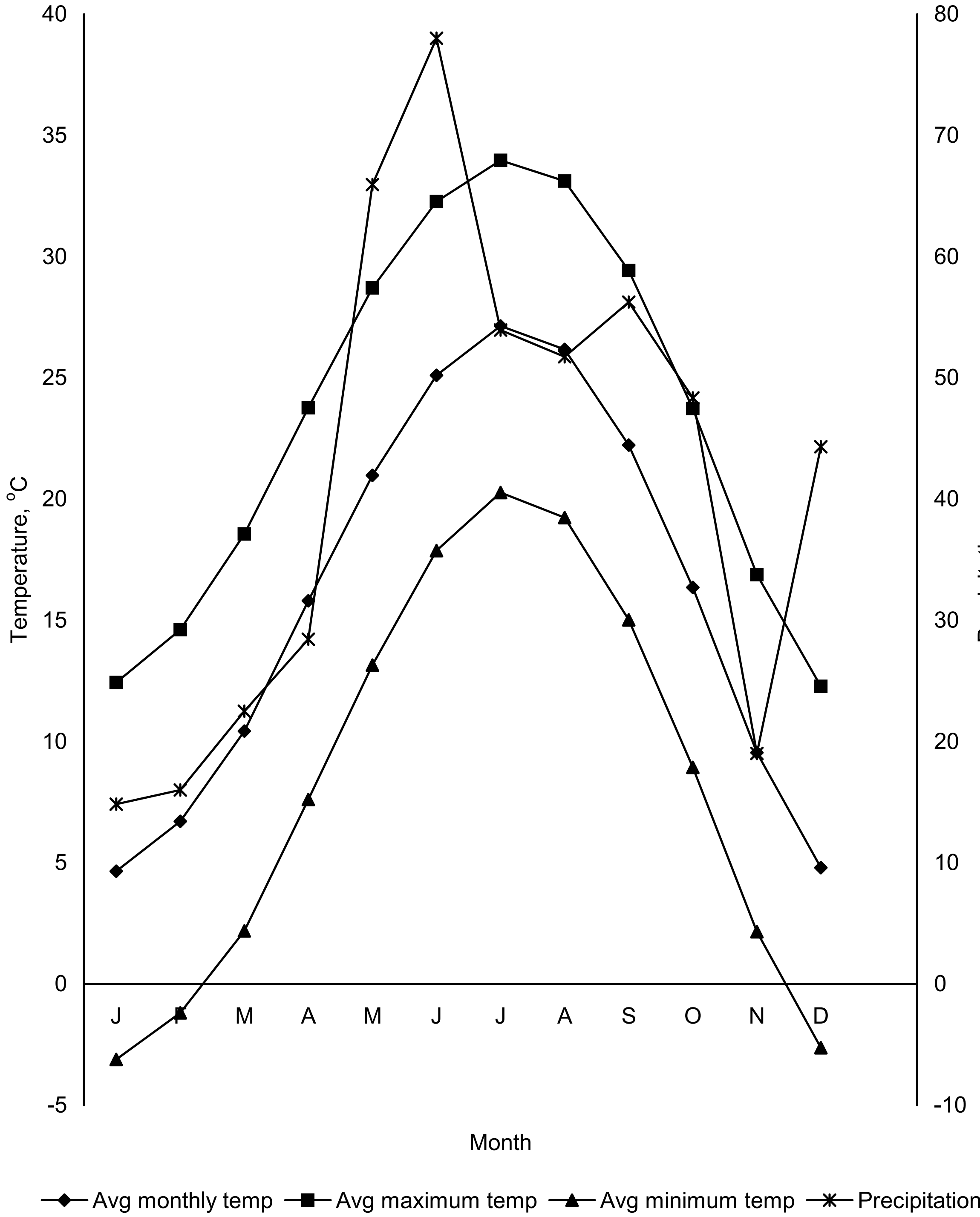

Fig. 2.1. Climatogram for Lubbock County, Texas (1948-2003).

Climax vegetation at the research site included blue grama and buffalo grass, with lesser amounts of mesquite, western wheatgrass, silver bluestem (*Bothriochloa laguroides*), wild alfalfa (*Psoralea tenuifolia*), and prairie clover (USDA-NRCS, 2003a; 2003b).

The current research was conducted for 3 yr, 2001 through 2003 (yr 4 through 6 of the long term project) in the cotton monoculture and integrated crop-livestock systems established in 1997. For the cotton monoculture 'Paymaster 2326 RR' cotton was planted in May and harvested in November of each yr. The integrated system included WW-B. Dahl as perennial forage. Cotton was in alternate yearly rotation with small grain rye and wheat for grazing by steers. WW-B. Dahl pasture was established in 1997. In order to achieve the yearly rotation of rye and wheat with cotton, 'Maton' rye was planted in September of each yr and was grazed the following winter and spring. In May, 'Paymaster 2326 RR' cotton, as part of the integrated system, was no-till planted into the rye. 'Lockett' wheat was planted in the autumn or early winter of each yr and grazed the following April-May. After grazing, the land was fallowed until rye was planted in September. Areas planted with rye in a given yr were planted with wheat the next year and vice versa. In the Integrated system, steers grazed sequentially dormant WW-B. Dahl, rye, and wheat from January to late May. At this time they were moved back to spring-growth WW-B. Dahl and were allowed to graze from late May to late July when they were sent to the feedyard for finishing. At the time this research began, three complete grazing seasons had occurred.

Each system was replicated three times in a complete randomized block design; each replication of the cotton monoculture occupied 0.24 ha, and those for the integrated system 3.9 ha. WW.B Dahl occupied 53% of the area of the integrated system and the small grain-cotton rotation occupied 47%, with half of the area being planted with cotton or fallowed after the winter and spring grazing. Seven Angus cross-breed steers (initial BW = 243 kg; SD = 19) grazed each replication of the integrated system from January to late July each year. Fertilization consisted of 60 kg ha^{-1} of N applied in the summer of each yr and 72 kg ha^{-1} of P applied in the summer of 2003.Irrigation and fertilizer applications were made through a sub-surface drip tape irrigation system buried at 1 m. (Fig 2.2).

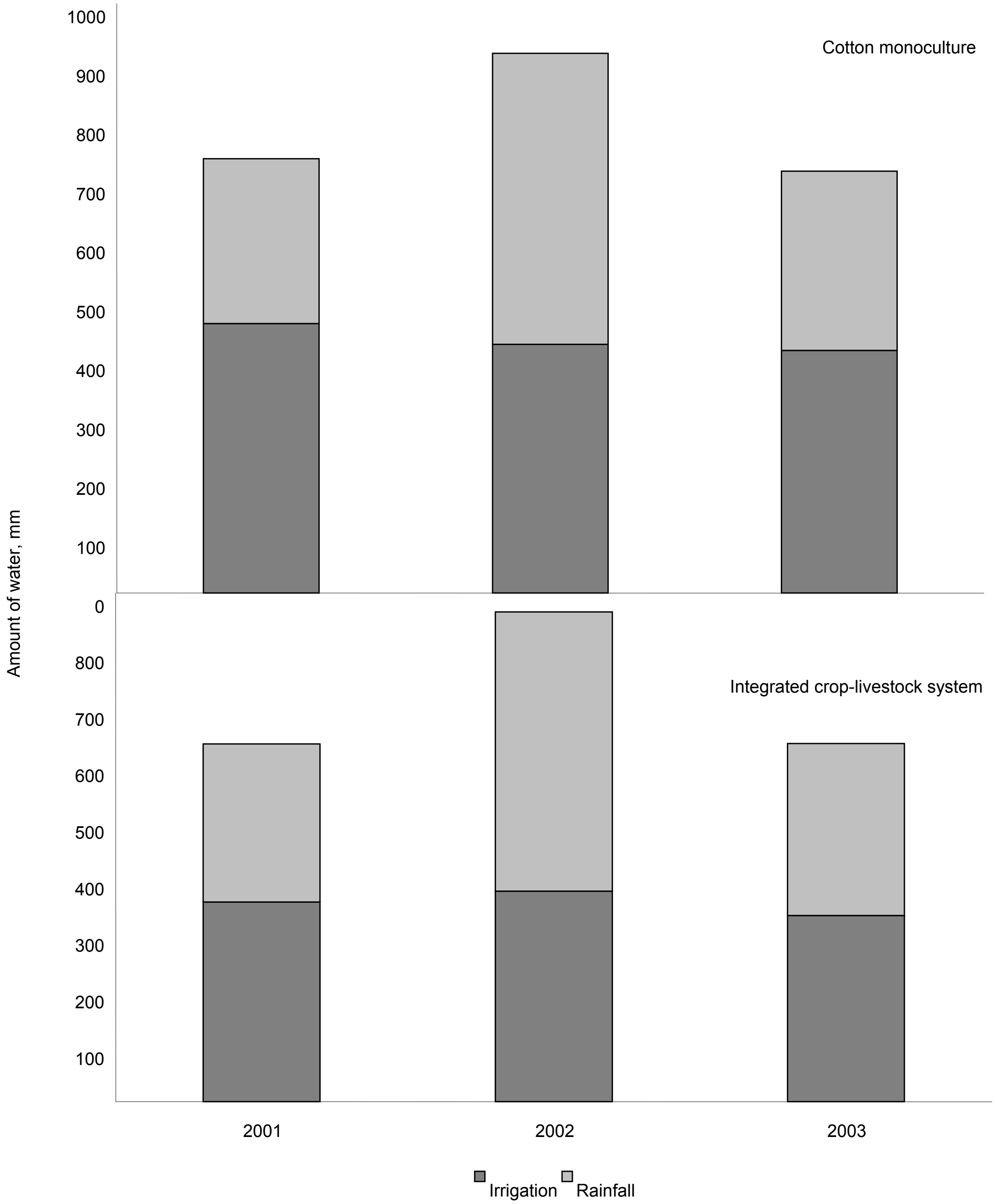

Fig. 2.2. Amount of water supplied through irrigation and precipitation to cotton monoculture and an integrated crop-livestock system that included WW-B. Dahl perennial pasture, a rye-cotton-wheat and a wheat-fallow-rye rotation in 2001, 2002, and 2003 at New Deal, TX.

Experiment 1. Effect of system and system component on extractable soil minerals and compaction

Soil samples were taken in May of 2001 and in December of 2003 in the cotton monoculture, and in the grazed rye, wheat, and WW-B. Dahl paddocks of the integrated crop-livestock system. In each paddock, eight samples were taken at each one of 0-5, 5-10, and then at 10-cm to 60 cm depth increments. At each depth interval the eight samples were mixed in order to obtain only one sample for each depth interval. The total soil samples collected were 168. Because sampling dates were 2 yr apart, crops in the integrated system rotation were in the same paddocks at each sampling yr. Nitrogen as nitrate was extracted at all seven depths using 2*M* KCl (Keeney and Nelson, 1987). Concentrations in solution were measured with an automated ion analyzer, QuikChem 8500 IC+ Option Flow Injection Analysis System (Lachat instruments, Hach Co., Loveland, CO.) Extractable P, Ca, Mg, K, Cu, Fe, Mn, and Zn were determined in the first four depth intervals (30 cm). Phosphorus was extracted using the method described by Olsen *et al*., (1954). Calcium, Mg, and K were extracted using the procedure described by Suarez (1996). Copper, Fe, Mn, and Zn were extracted following the methodology indicated by Reed and Martens (1996). Concentrations in solution of P, Ca, Mg, K, Cu, Fe, Mn, and Zn were measured by atomic emission with a Thermo Jarred-Ash inductively coupled plasma spectrophotometer (Thermo Jarred-Ash Co., Franklin, MA, USA).

In 2003, soil compaction was determined in February, and November following the harvest of WW-B. Dahl seed. For each date and in the same areas where soil samples were collected, 52 compaction readings were taken with a Chatillon conical penetrometer (John Chatillon & Sons, Kew Garden, NY, USA).

Statistical analyses for extractable soil minerals were as a completely randomized block design with a split-split-plot arrangement of the system and integrated system components (Steel and Torrie, 1981). For soil compaction, the statistical analysis was as a completely randomized block design with a split-plot arrangement of the treatments (Steel and Torrie, 1981). Effects of treatments on response variables were tested using the GLM procedure of SAS (SAS, 1999). Means were separated by Tukey's test (Steel and Torrie, 1981).

Differences among systems and integrated system components were further tested by orthogonal contrasts to compare 1) cotton monoculture vs. the mean of the integrated crop-livestock system components, 2) the WW-B. Dahl vs. the mean of the wheat and rye components, and 3) wheat vs. rye.

Experiment 2. Effect of grazing vs. no grazing by steers on extractable soil minerals and compaction

Since the start of the project in 1997, two grazing treatments were imposed on the integrated system components: 1) non-grazing and 2) long-term grazing. For the non-grazing treatment a 4.8 x 4.8 m exclusion cage was randomly located within the pasture, thus, from the time of initial establishment, no grazing activity had occurred in this area. The long-term grazing period was the total length of the rye, wheat, and WW-B. Dahl grazing season each yr. Averaged over the 6 yr of the project, this was 49, 40, 23, and 60 d for dormant WW-B. Dahl, rye, wheat and green WW-B. Dahl, respectively (Table 2.1). For all treatments, the same areas were maintained under the same treatment over the duration of the current research as well as all previous yr of the project.

Soil samples were taken in May of 2001 and in December of 2003 in the non-grazed and in the grazed rye, wheat, and WW-B. Dahl paddocks of the integrated crop-livestock system. In each paddock, eight samples at the first 0-5 cm were taken and combined. The total soil samples collected were 36. Nitrogen as nitrate P, Ca, Mg, K, Cu, Fe, Mn, and Zn were measured following the methodologies described in the previous section. Soil compaction was determined on the same dates and using the same procedure as in the previous experiment.

For extractable soil minerals, statistical analysis was as a completely randomized block design with a split-split-plot arrangement of the treatments (Steel and Torrie, 1981). For soil compaction, the statistical analysis was as a completely randomized block design with a split-plot arrangement of the treatments (Steel and Torrie, 1981). Effects of treatments on response variables were tested using the GLM procedure of SAS (SAS, 1999). Means were separated by Tukey’s test (Steel and Torrie, 1981).

Table 2.1. Days steer grazed WW-B. Dahl old world bluestem, rye and wheat in an integrated crop-livestock system at New Deal, TX from 2001 to 2003.

Forage	Year			Mean
	2001	2002	2003	
	-----------------------Days grazed----------------------			
WW-B. Dahl				
Dormant	47	67	33	49
Spring growth	53	71	57	60
Maton rye	45	31	45	40
Lockett wheat	23	22	25	23

Experiment 3. Effect of three grazing intervals on WW-B. Dahl on extractable soil minerals and compaction

Since the start of the project in 1997, two grazing treatments were imposed on the WW-B. Dahl component of the integrated crop-livestock system: 1) non-grazing and 2) long-term grazing. In May 2001, A short-term grazing treatment was also imposed. For the non-grazing treatment a 4.8 x 4.8 m exclusion cage was randomly located within the pasture, thus, from the time of initial establishment, no grazing activity had occurred in this area. For the short-term grazing period, a 4.8 x 4.8 m exclusion cage was randomly located within the pasture in late June. At the end of the grazing season this cage was removed until the following June and was replaced at the same site. The long-term grazing period was the total length of the grazing season each yr. Averaged over the 3 yr of the project, grazing periods were 0, 38, and 60 d for the non-grazing, short-term grazing and long-term grazing treatments, respectively (Table 2.2). For all treatments, the same areas were maintained under the same treatment over the duration of the current research as well as all previous yr of the project for treatments 1 and 3.

Soil samples were taken in May of 2001 and in December of 2003 in the non-grazed and in the grazed WW-B. Dahl paddocks of the integrated crop-livestock system. In each paddock, eight samples at the first 0-5 cm were taken and combined. The total soil samples collected were 18.

For extractable soil minerals, collection of soil samples and laboratory analyses were similar to those described in the previous section, however in this experiment Na extracted following the procedure described by Suarez (1996) was also included. Additionally, soil compaction was determined in June and July of 2002 and in February, June, July, and November following the harvest of WW-B. Dahl seed of 2003. Compaction readings were taken as described above.

For extractable soil minerals and soil compaction, statistical analysis was as a completely randomized block design with a split-plot arrangement of the treatments (Steel and Torrie, 1981). Effects of treatments on response variables were tested using the GLM procedure of SAS (SAS, 1999). Means were separated by Tukey's test (Steel and Torrie, 1981).

Differences among WW-B. Dahl grazing treatments were further tested by orthogonal contrasts to compare 1) non-grazing areas vs. the mean of grazed areas and 2) short-term grazing period vs. long-term period.

Table 2.2. Days steer grazed WW-B. Dahl old world bluestem, at three grazing terms, at New Deal, TX, from 2001 to 2003.

Grazing term	Year 2001	2002	2003	Mean
	----------------------Days grazed-----------------------			
Non-grazed	0	0	0	0
Short grazed period	38	45	30	38
Long grazed period	53	71	57	60

Results

Experiment 1. Effect of system and system components on extractable soil minerals and compaction

Extractable soil minerals

Effects of the cotton monoculture and the integrated crop-livestock system on extractable soil NO_3^--N P, Ca, K, Mg, Cu, Fe, and Mn depended on sampling date (date by system component interaction; $P < 0.05$), thus, results for each system component at a given sampling date were analyzed separately. Effects of system on extractable Zn did not depend on sampling date, thus, results for this mineral were analyzed across sampling dates.

In May 2001, extractable NO_3^--N in soils from the cotton monoculture was higher ($P < 0.05$) than the mean of soils from the integrated system (Fig 2.3). Extractable NO_3^--N in soils from WW-B. Dahl was lower ($P < 0.05$) than the mean concentration of rye-cotton-wheat and wheat-fallow-rye rotation. Extractable soil NO_3^--N was similar for the cotton monoculture, rye-cotton-wheat, and wheat-fallow-rye. In December 2003, there were no differences ($P > 0.05$) in extractable NO_3^--N concentration between soils from the cotton monoculture and the mean of soils from the integrated system. Extractable NO_3^--N in soils from WW-B. Dahl was lower ($P < 0.05$) than the mean concentration of rye-cotton-wheat and wheat-fallow-rye rotation. When analyzed individually, WW-B. Dahl had the lowest ($P < 0.05$) extractable NO_3^--N while rye-cotton-wheat had the highest concentration ($P < 0.05$) of all four areas sampled. Extractable NO_3^--N was similar in soils from the cotton monoculture and wheat-fallow-rye.

In May 2001, extractable P in soils from the cotton monoculture was lower (*P* < 0.05) than the mean of soils from the integrated system (Fig 2.4). Extractable P in soils from WW-B. Dahl was not different (*P* > 0.05) from the mean concentration of rye-cotton-wheat and wheat-fallow-rye rotation; however, extractable P from rye-cotton-wheat was higher (*P* < 0.05) than in wheat-fallow-rye rotation. In December 2003, extractable P in soils from the cotton monoculture was higher (*P* < 0.05) than the mean of soils from the integrated system. Extractable P within the integrated system did not differ among components (*P* > 0.05).

In May 2001, no differences (*P* > 0.05) were observed in extractable K and Ca between systems (Fig 2.5-2.6). Extractable Mg in soils from the cotton monoculture was lower (*P* < 0.05) than the mean of soils from the integrated system components (Fig 2.7). There were no further differences in extractable K. There were no differences (*P* > 0.05) in extractable Ca and Mg between soils from WW-B. Dahl and the mean concentration rye-cotton-wheat and wheat-fallow-rye rotation but extractable Ca from rye-cotton-wheat was lower (*P* < 0.05) than in wheat-fallow-rye while extractable Mg was higher (*P* < 0.05) in soils from rye-cotton-wheat than in soils from wheat-fallow-rye.

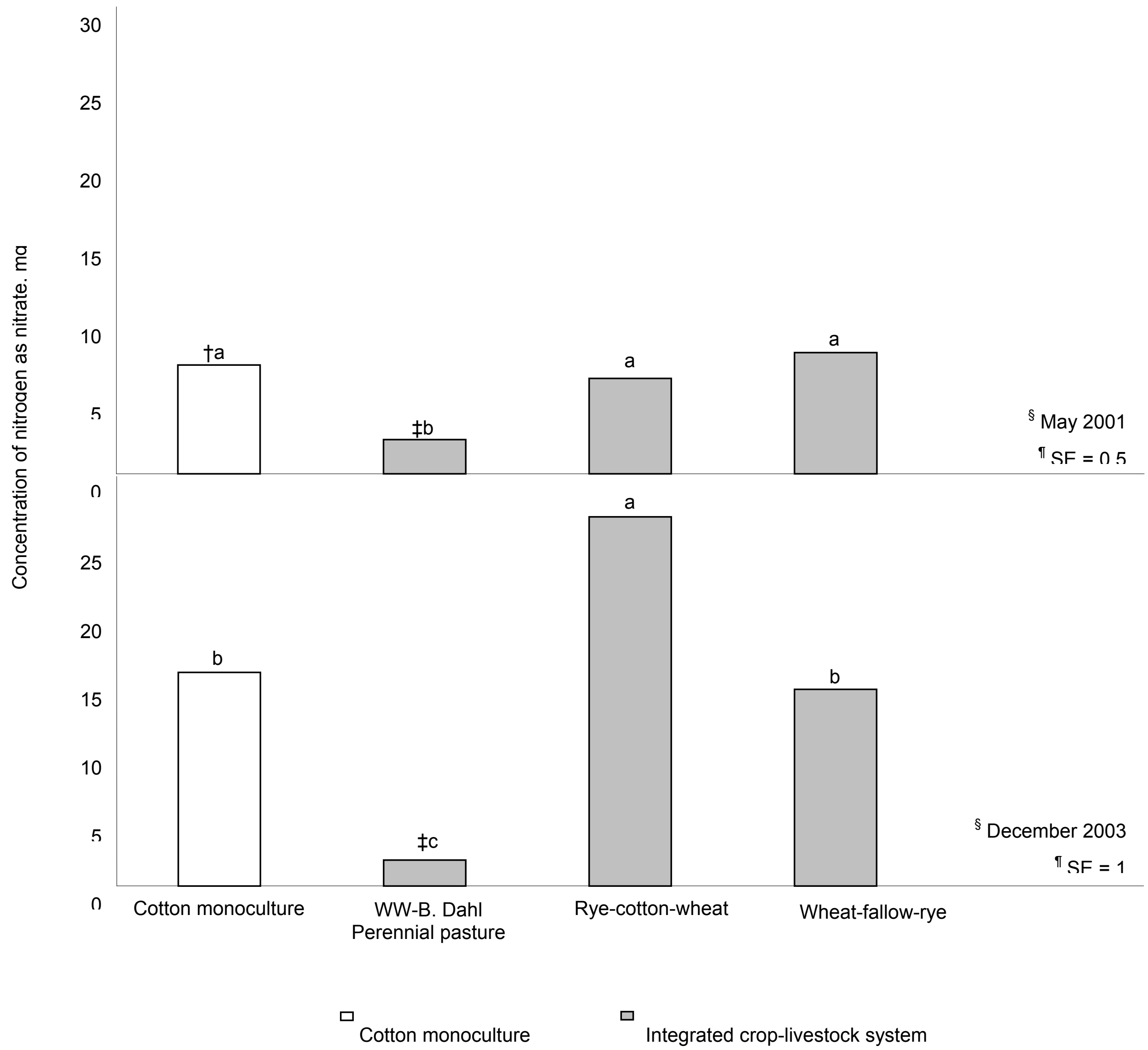

Fig. 2.3. Extractable soil nitrogen as nitrate averaged over the first 30 cm of soils from a cotton monoculture and an integrated crop-forage-livestock system that included WW-B. Dahl perennial pasture, a rye-cotton-wheat and a wheat-fallow-rye rotation in May 2001 and December 2003 at New Deal, TX. † Indicates difference ($P < 0.05$) between soils from the cotton monoculture and the mean of soils from the crop-livestock system. a,b,c Means with the same letter were not different ($P > 0.05$). ‡ Indicates differences ($P < 0.05$) between soils from the rye-cotton-wheat and wheat-fallow-rye rotation. § Indicate a date by system component interaction ($P < 0.05$). ¶ SE = standard error of the mean.

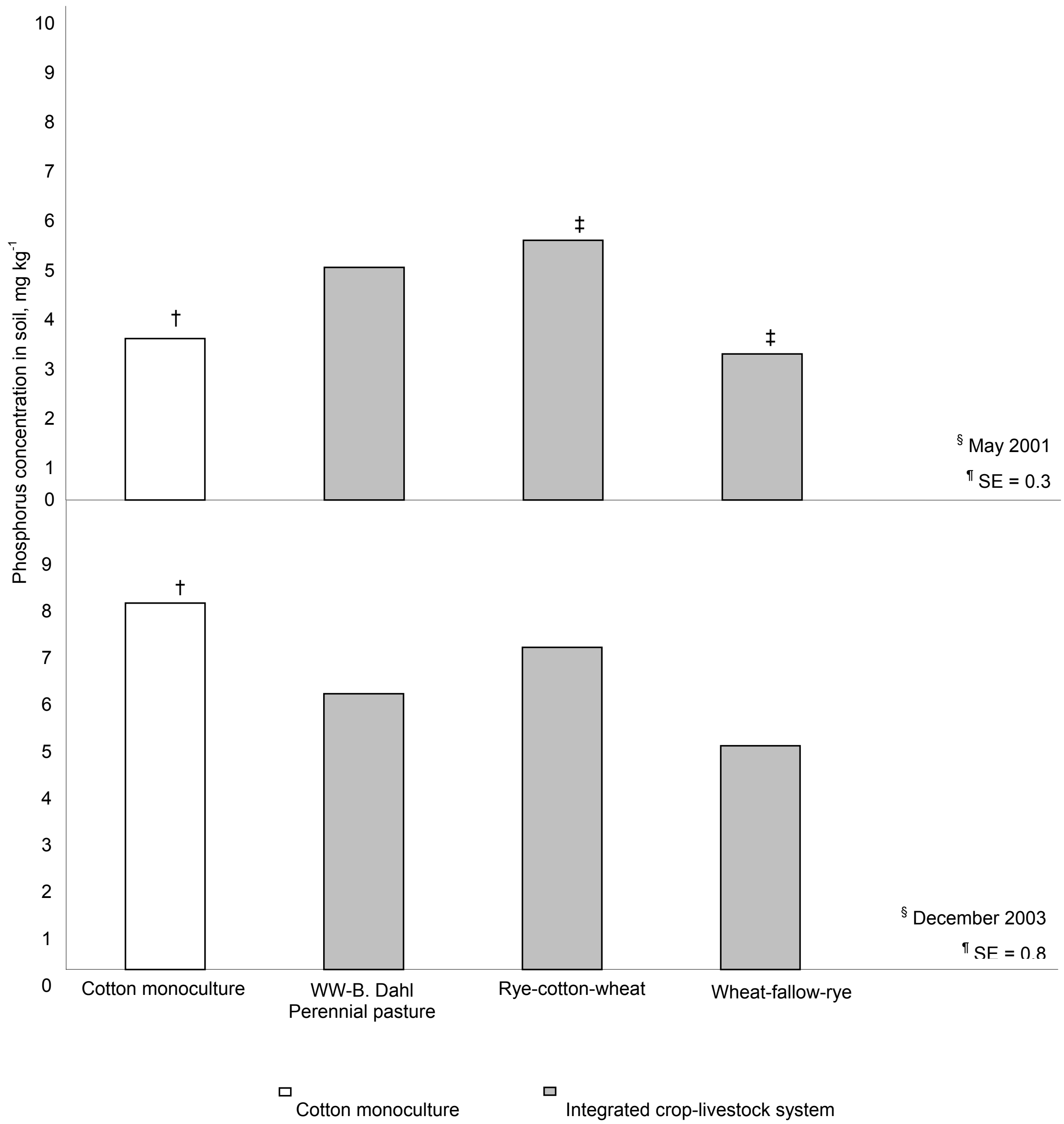

Fig. 2.4. Extractable soil phosphorus averaged over the first 30 cm of soils from a cotton monoculture and an integrated crop-forage-livestock system that included WW-B. Dahl perennial pasture, a rye-cotton-wheat and a wheat-fallow-rye rotation in May 2001 and December 2003 at New Deal, TX. † Indicates difference (P < 0.05) between soils from the cotton monoculture and the mean of soils from the crop-livestock system. ‡ Indicates differences (P < 0.05) between soils from the rye-cotton-wheat and wheat-fallow-rye rotation. § Indicate a date by system component interaction (P < 0.05). ¶ SE = standard error of the mean.

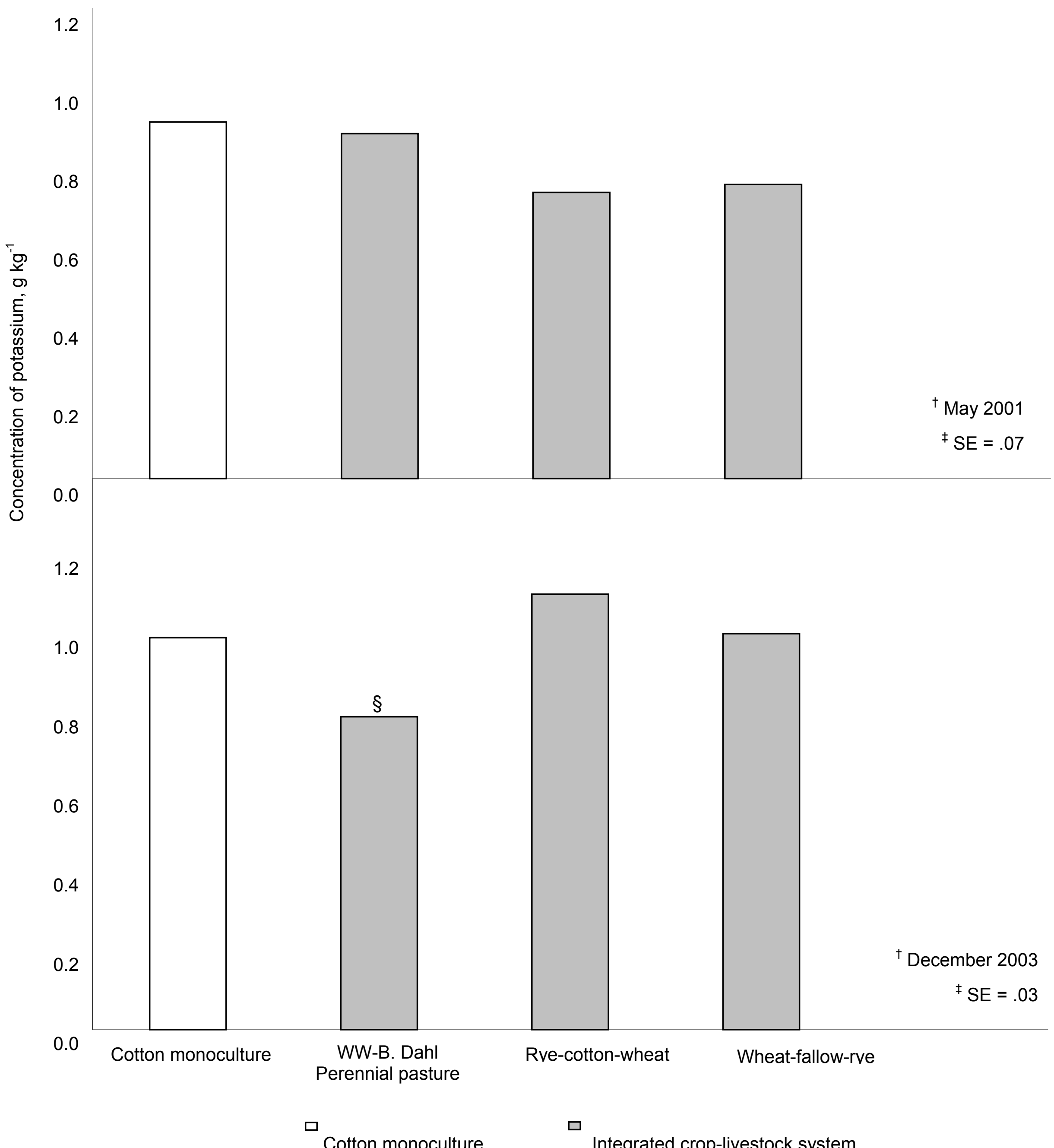

Fig. 2.5. Extractable soil potassium averaged over the first 30 cm of soils from a cotton monoculture and a crop-livestock system that included WW-B. Dahl perennial pasture, a rye-cotton-wheat and a wheat-fallow-rye rotation in May 2001 and December 2003 at New Deal, TX.

† Indicates a date by system component interaction ($P < 0.05$). ‡ SE = standard error of the mean. § Indicates differences ($P < 0.05$) between the soils from WW-B. Dahl perennial pasture and the mean of soils from the rye-cotton-wheat and wheat-fallow-rye rotation.

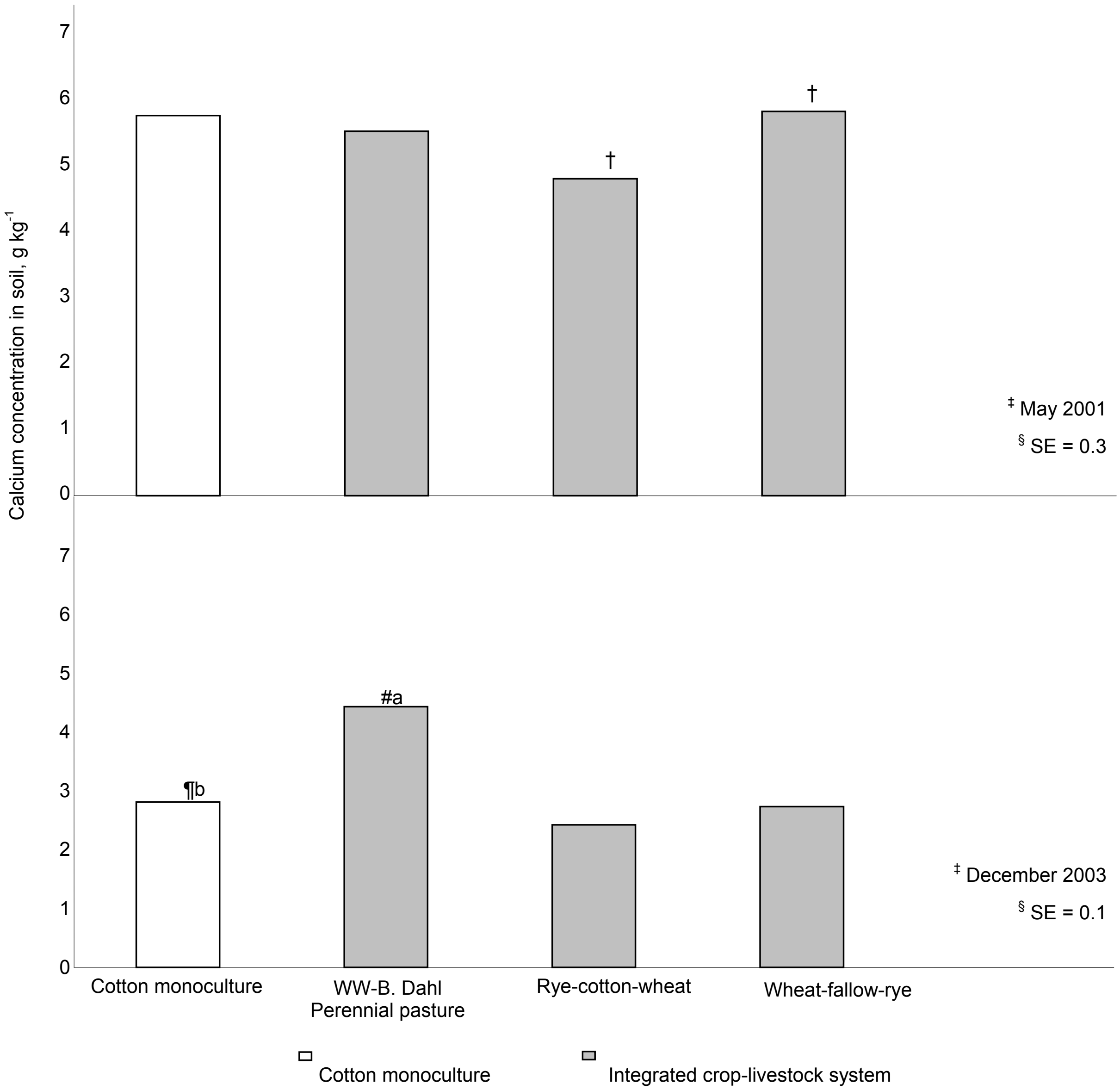

Fig. 2.6. Extractable soil calcium averaged over the first 30 cm of soils from a cotton monoculture and a crop-livestock system that included WW-B. Dahl perennial pasture, a rye-cotton-wheat and a wheat-fallow-rye rotation in May 2001 and December 2003 at New Deal, TX.

† Indicates differences ($P < 0.05$) between soils from the rye-cotton-wheat and wheat-fallow-rye rotation. ‡ Indicate a date by system component interaction ($P < 0.05$). § SE = standard error of the mean. ¶ Indicates differences ($P <$ 0.05) between soils from the cotton monoculture and the mean of soils from the forage-crop-livestock system. [a,b] Means with the same letter were not different ($P > 0.05$). # Indicates differences ($P < 0.05$) between the soils from WW-B. Dahl perennial pasture and the mean of soils from the rye-cotton-wheat and wheat-fallow-rye rotation.

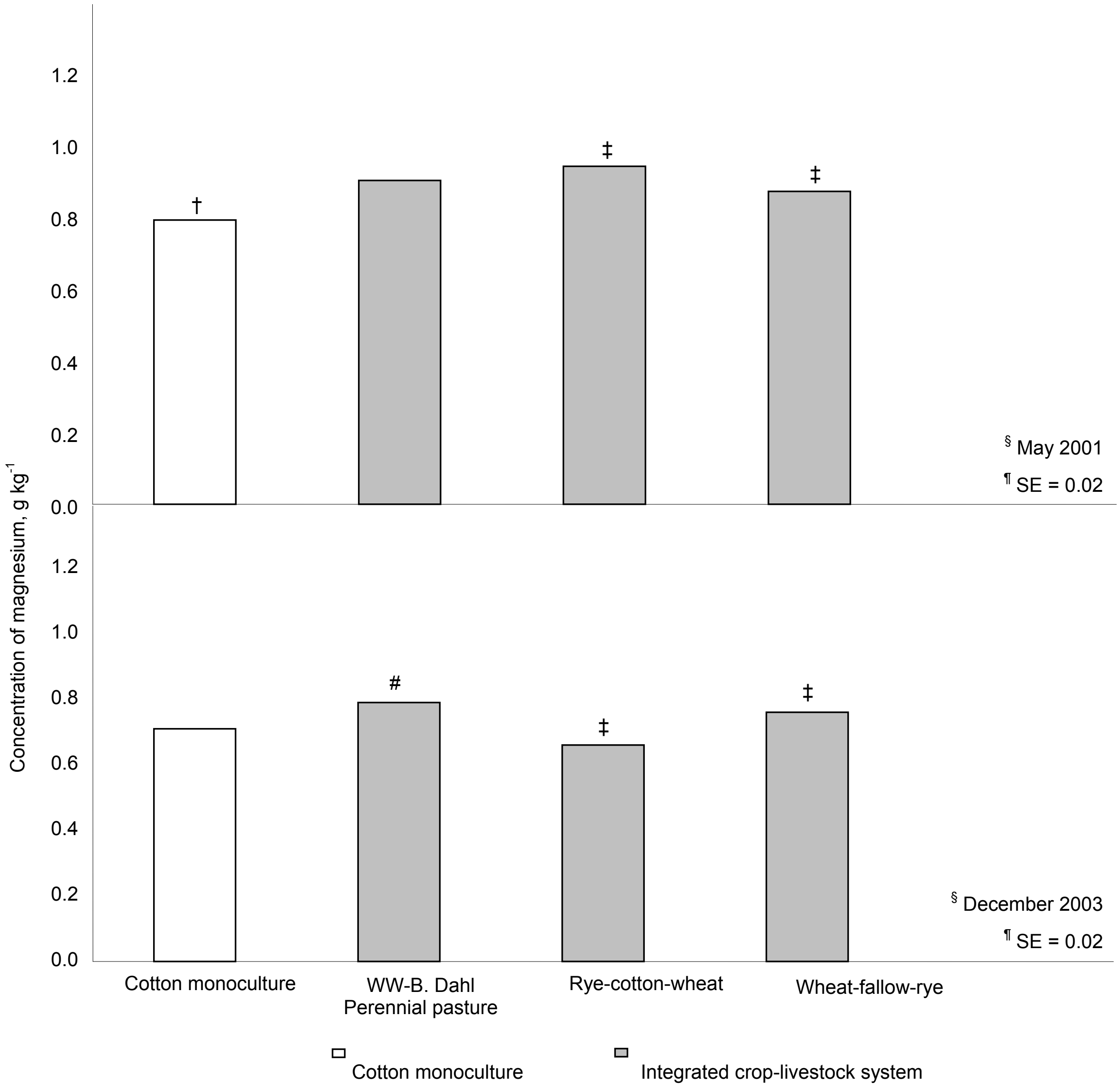

Fig. 2.7. Extractable soil magnesium averaged over the first 30 cm of soils from a cotton monoculture, and an integrated crop-livestock system that included WW-B. Dahl perennial pasture, a rye-cotton-wheat, and a wheat-fallow-rye rotation in May 2001 and December 2003 at New Deal, TX.

[†] Soil from cotton monoculture was different ($P < 0.05$) from the averaged means of soils from WW-B. Dahl perennial pasture, rye-cotton-wheat and wheat-fallow-rye rotations. [‡] Within a year indicate differences ($P \leq 0.05$) between the means of soils from rye-cotton-wheat and wheat-fallow-rye rotations. [§] Indicates a date by system component interaction ($P < 0.05$). [¶] SE = standard error of the mean. [#] Soil from WW-B. Dahl perennial pasture was different ($P < 0.05$) from the averaged means of soils from rye-cotton-wheat and wheat-fallow-rye rotation.

In December 2003, extractable K in soils from WW-B. Dahl was lower (P < 0.05) than the mean in soils from rye-cotton-wheat and wheat-fallow-rye rotation. No other differences were observed.

In December 2003, extractable Ca in soils from the cotton monoculture was lower (P < 0.05) than the mean of soils from the integrated system components but this was due to the high extractable Ca concentration in soils from WW-B. Dahl. Extractable Ca in soils from WW-B. Dahl was higher (P < 0.05) than the mean concentration of rye-cotton-wheat and wheat-fallow-rye rotation but rye-cotton-wheat Ca concentration did not differ (P > 0.05) from that in wheat-fallow-rye.

In December 2003, extractable Mg in soils from the cotton monoculture was not different (P > 0.05) than the mean of soils from the integrated system components. Extractable Mg in soils from WW-B. Dahl was higher (P < 0.05) from the mean concentration of rye-cotton-wheat and wheat-fallow-rye rotation. Extractable Mg in soils from rye-cotton-wheat was higher (P < 0.05) than in wheat-fallow-rye.

Extractable Cu, Fe, and Mn in soils from the cotton monoculture were higher (P < 0.05) than the mean of soils from the integrated system components (Fig 2.8-2.10) in May 2001. Extractable Cu and Fe in the cotton monoculture were also higher (P < 0.05) than extractable Cu and Fe on soils from each component of the integrated system. Extractable Mn in soils from the cotton monoculture was only higher (P < 0.05) than extractable Mn in soils from WW-B. Dahl and wheat-fallow-rye rotation. Extractable Cu and Mn in soils from rye-cotton-wheat were higher (P <

0.05) than concentrations of these minerals from either WW-B. Dahl or wheat-fallow-rye soils. Extractable Fe in soils from WW-B. Dahl was lower (P < 0.05) than the mean concentration of rye-cotton-wheat and wheat-fallow-rye rotation and was also lower (P < 0.05) than extractable Fe in soils from rye-cotton-wheat, but was similar to extractable Fe in soils from wheat-fallow-rye. Extractable Fe in soils from rye-cotton-wheat was higher (P < 0.05) than in wheat-fallow-rye. In December 2003, there were no differences (P > 0.05) in extractable Cu or Fe between soils from the cotton monoculture and the integrated system while extractable Mn in soils from the cotton monoculture was higher (P < 0.05) than the mean of soils from the integrated system components. No differences (P > 0.05) were observed in extractable Cu, Fe, or Mn among the integrated system components. Extractable soil Zn was not different (P > 0.05) among systems, system components or among years and averaged 0.3 mg kg^{-1} (data not shown).

For all minerals, except NO_3^--N, soil depth and sampling date influenced (P < 0.05) mineral concentration but their effects were consistent among systems and system components (no date by depth interaction; P > 0.05), thus, soil concentration of P, Ca, K, Mg, Cu, Fe, Mn, and Zn at each depth on a given sampling date were averaged across systems and system component.

The effect of soil depth and date of sampling on NO_3^--N varied (P < 0.05) accordingly to each system component (depth by date and depth by system component interactions; P < 0.05; Fig 2.11); however differences between yr were only in magnitude.

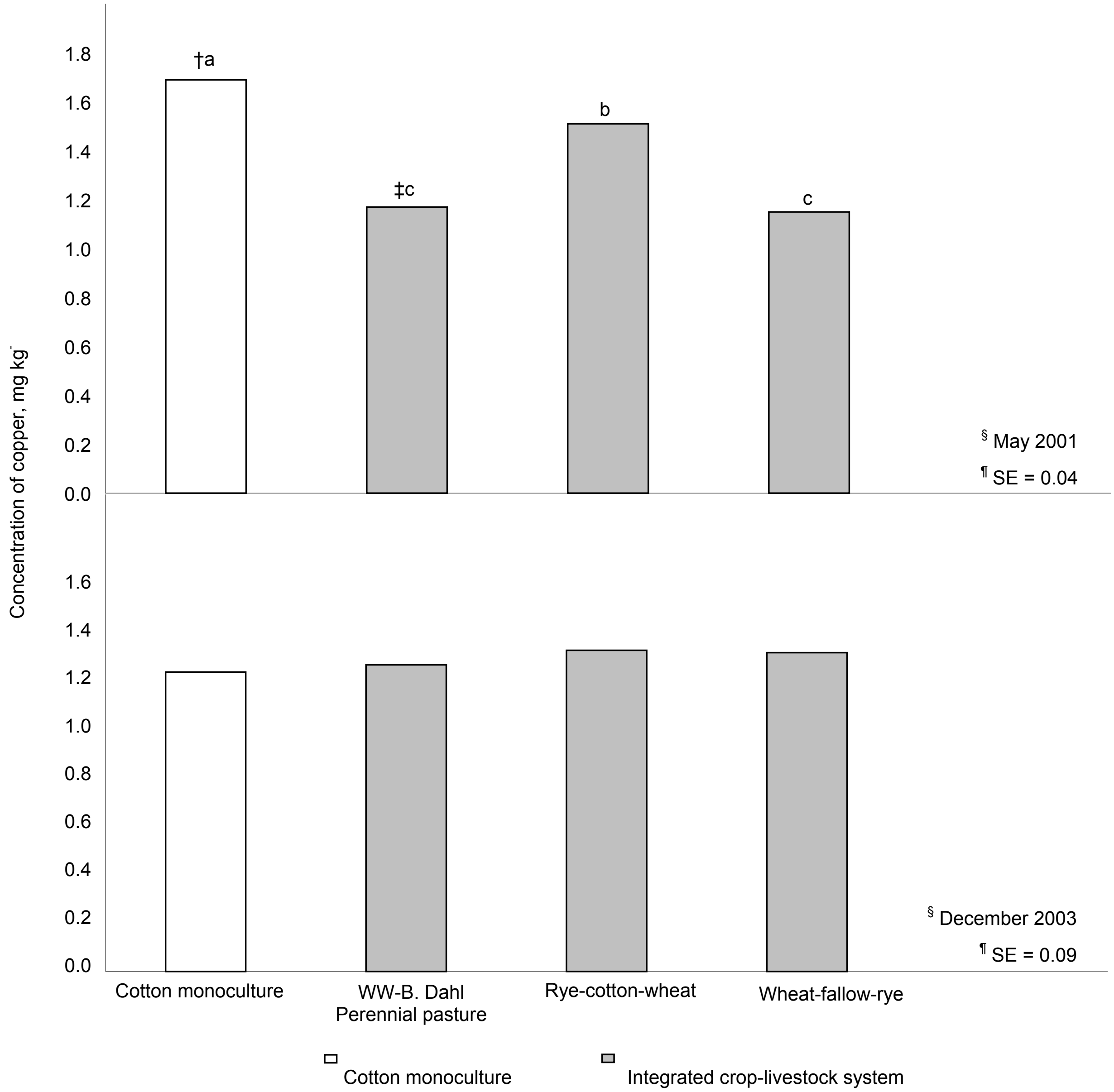

Fig. 2.8. Extractable soil copper averaged over the first 30 cm of soils from a cotton monoculture, and an integrated crop-livestock system that included WW-B. Dahl perennial pasture, a rye-cotton-wheat, and a wheat-fallow-rye rotation in May 2001 and December 2003 at New Deal, TX.
[†] Indicates difference ($P < 0.05$) between soils from the cotton monoculture and the mean of soils from the crop-forage-livestock system. [a,b,c] Means with the same letter were not different ($P > 0.05$). [‡] Indicates differences ($P < 0.05$) between the soils from WW-B. Dahl perennial pasture and the mean of soils from the rye-cotton-wheat and wheat-fallow-rye rotation. [§] Indicates a date by system component interaction ($P < 0.05$). [¶] SE = standard error of the mean.

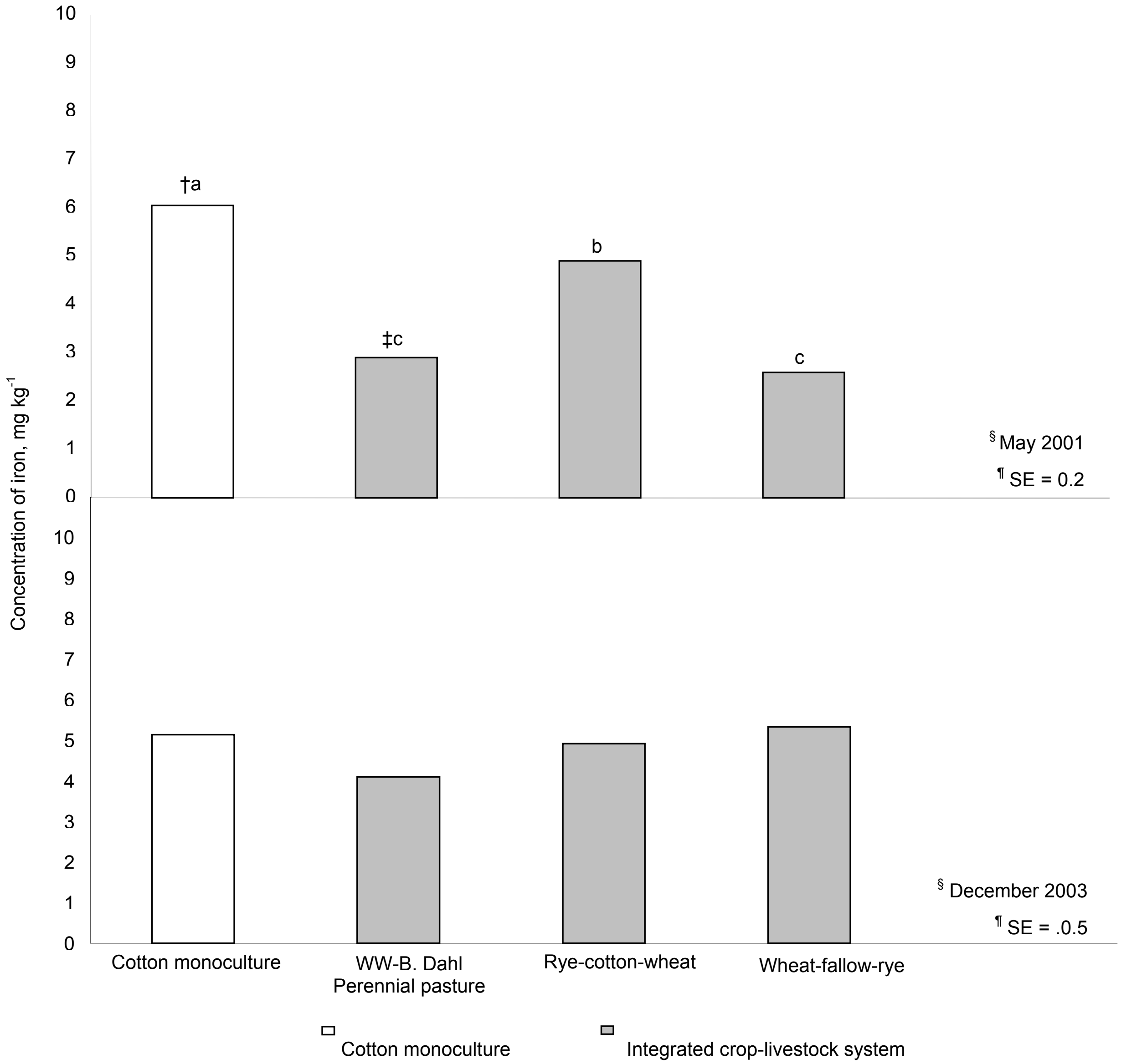

Fig. 2.9. Extractable soil iron averaged over the first 30 cm of soils from a cotton monoculture, and an integrated crop-livestock system that included WW-B. Dahl perennial pasture, a rye-cotton-wheat, and a wheat-fallow-rye rotation in May 2001 and December 2003 at New Deal, TX.

† Indicates difference ($P < 0.05$) between soils from the cotton monoculture and the mean of soils from the crop-livestock system. a,b,c Means with the same letter within a year were not different ($P > 0.05$). ‡ Indicates differences ($P < 0.05$) between the soils from WW-B. Dahl perennial pasture and the mean of soils from the rye-cotton-wheat and wheat-fallow-rye rotation. § Indicates a date by system component interaction ($P < 0.05$). ¶ SE = standard error of the mean.

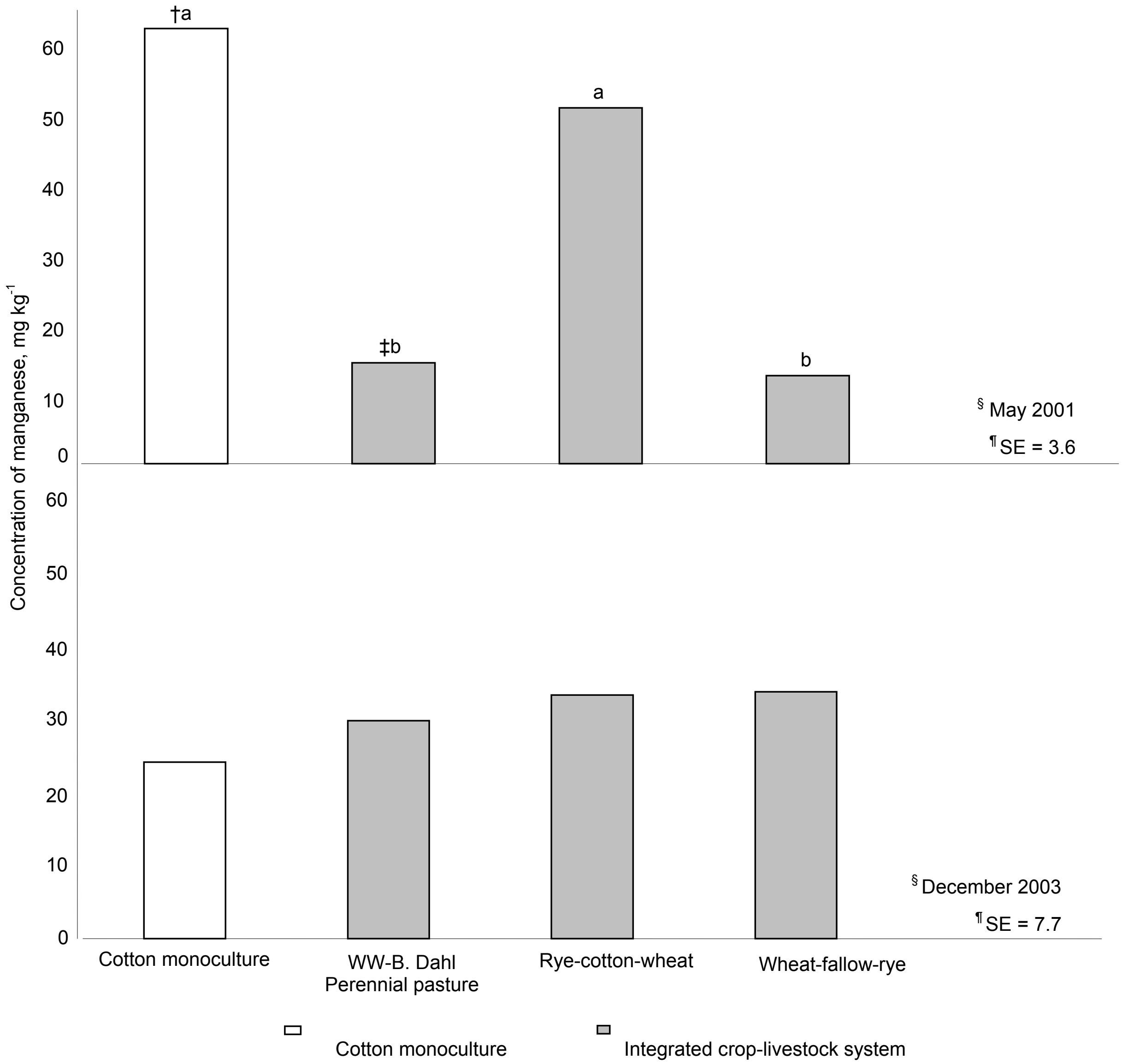

Fig. 2.10. Extractable soil manganese averaged over the first 30 cm of soils from a cotton monoculture, and an integrated crop-livestock system that included WW-B. Dahl perennial pasture, a rye-cotton-wheat, and a wheat-fallow-rye rotation in May 2001 and December 2003 at New Deal, TX.
† Indicates difference (P < 0.05) between soils from the cotton monoculture and the mean of soils from the crop-forage-livestock system. [a,b,c] Means with the same letter within a year were not different (P > 0.05). ‡ Indicates differences (P < 0.05) between the soils from WW-B. Dahl perennial pasture and the mean of soils from the rye-cotton-wheat and wheat-fallow-rye rotation. § Indicates a date by system component interaction (P < 0.05). ¶ SE = standard error of the mean.

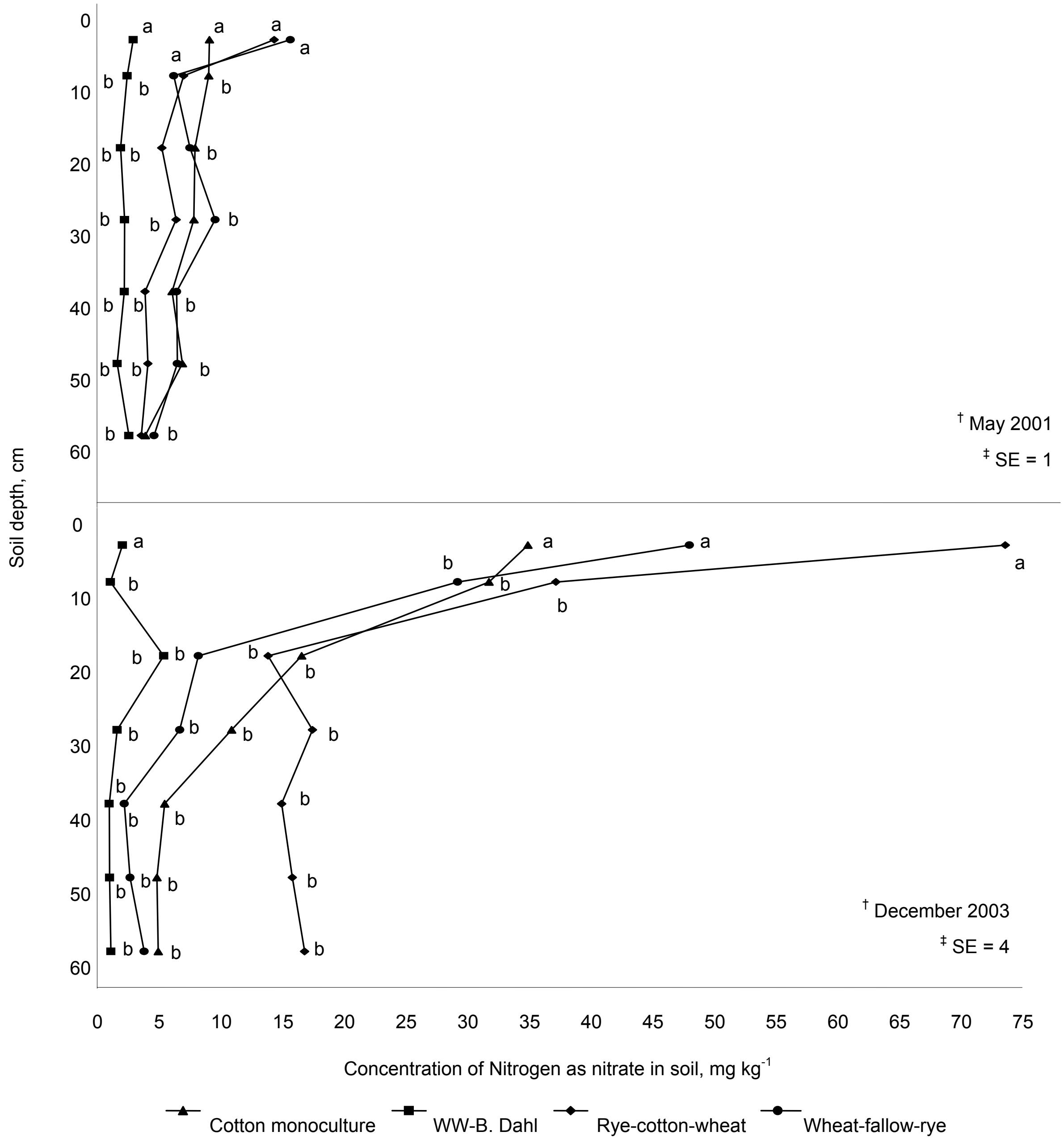

Fig. 2.11. Extractable soil nitrogen as nitrate at different soil depths from a cotton monoculture and an integrated crop-livestock system that included WW-B. Dahl perennial pasture, a rye-cotton-wheat and a wheat-fallow-rye rotation in May 2001 and December 2003 at New Deal TX.

[a,b] Means with the same letter within a system component were not different ($P > 0.05$). † Indicate a date by system component and a depth by system component interactions ($P < 0.05$). ‡ SE = Standard error of the mean.

Extractable NO_3^--N was higher in December 2003, than in May of 2001. For both yr highest NO_3^--N was found in the first 5 cm, with a decline in the 5-10 cm intervals, and no further decline with depth observed in May 2001; however, in December 2003, the decline was noticed also at 10-20 cm.

Extractable P and K were higher ($P < 0.05$) in soils sampled in December 2003 than in May 2001, while the opposite occurred for Ca and Mg, both were higher ($P < 0.05$) in soils sampled in May 2001 than in December 2003. For both yr the highest ($P < 0.05$) extractable P and K occurred in the first 5 cm (Fig 2.12-2.14). Extractable P did not differ among lower soil depths but extractable K declined within depth to 20 cm below. Conversely, the highest ($P < 0.05$) extractable Ca occurred at 30 cm. Extractable Mg was constant ($P > 0.05$) throughout the profile (Fig 2.15).

In May 2001, extractable Cu, Fe, and Mn were generally higher ($P < 0.05$) in the surface 5 cm than at lower depths (Fig 2.16-2.18). with higher ($P < 0.05$) surface concentrations than at 5-10 or 10-20 cm increments. Soil concentrations of these minerals at 20-30 cm were similar to that found in the surface samples. No difference ($P > 0.05$) within depth was observed in December 2003 for extractable Cu, Fe and Mn. Extractable Zn did not differ ($P > 0.05$) between sampling date but highest ($P < 0.05$) extractable Zn occurred at 0-5 cm with no differences ($P > 0.05$) among lower depths (Fig 2.19).

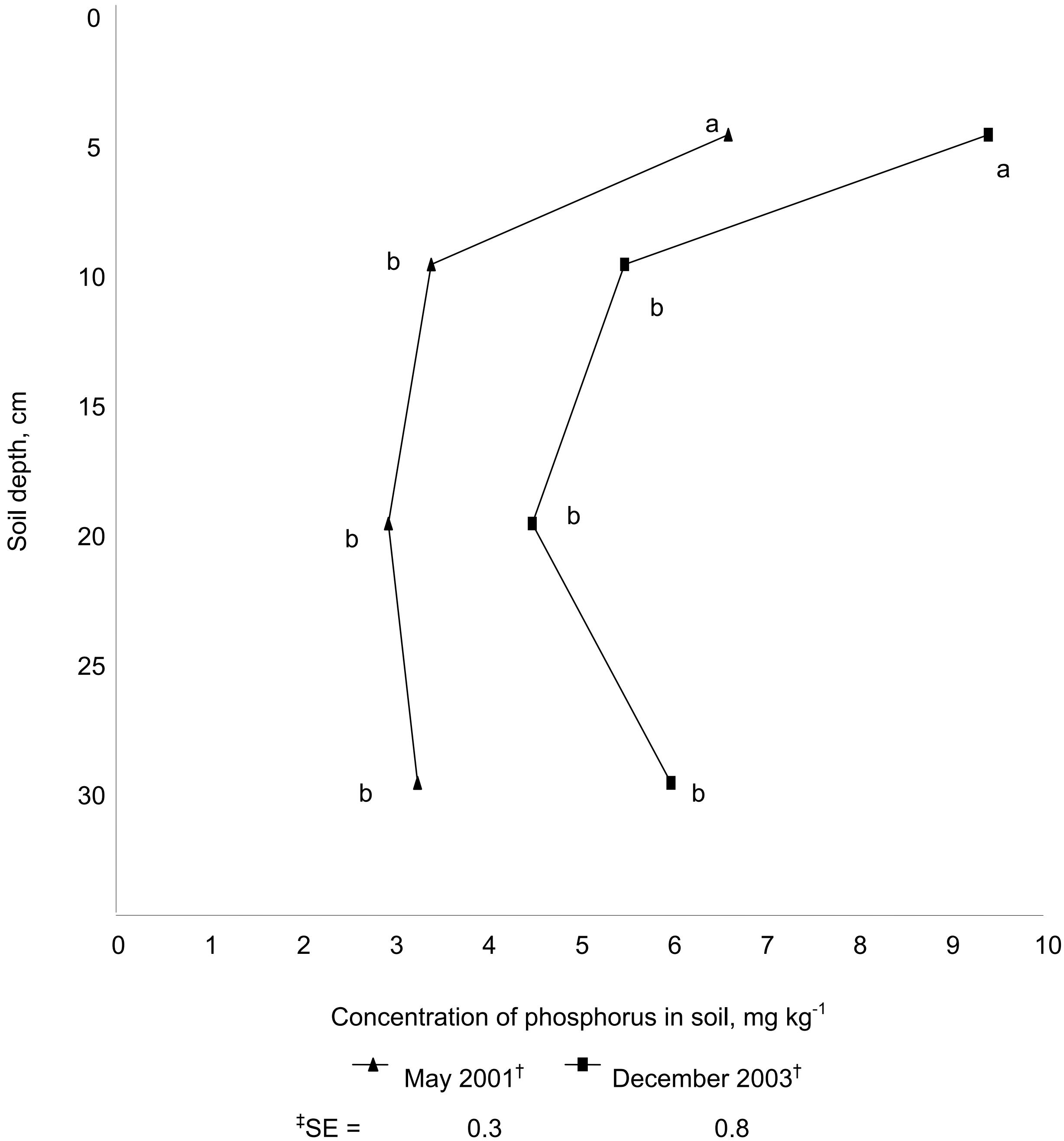

Fig. 2.12. Extractable soil phosphorus at different soil depths, averaged across a cotton monoculture and an integrated crop-livestock system that included WW-B. Dahl perennial pasture, a rye-cotton-wheat and a wheat-fallow-rye rotation in May 2001 and December 2003 at New Deal TX.
[a,b] Means with the same letter within a year were not different ($P > 0.05$). ‡SE = Standard error of the mean. † Date effect ($P < 0.05$).

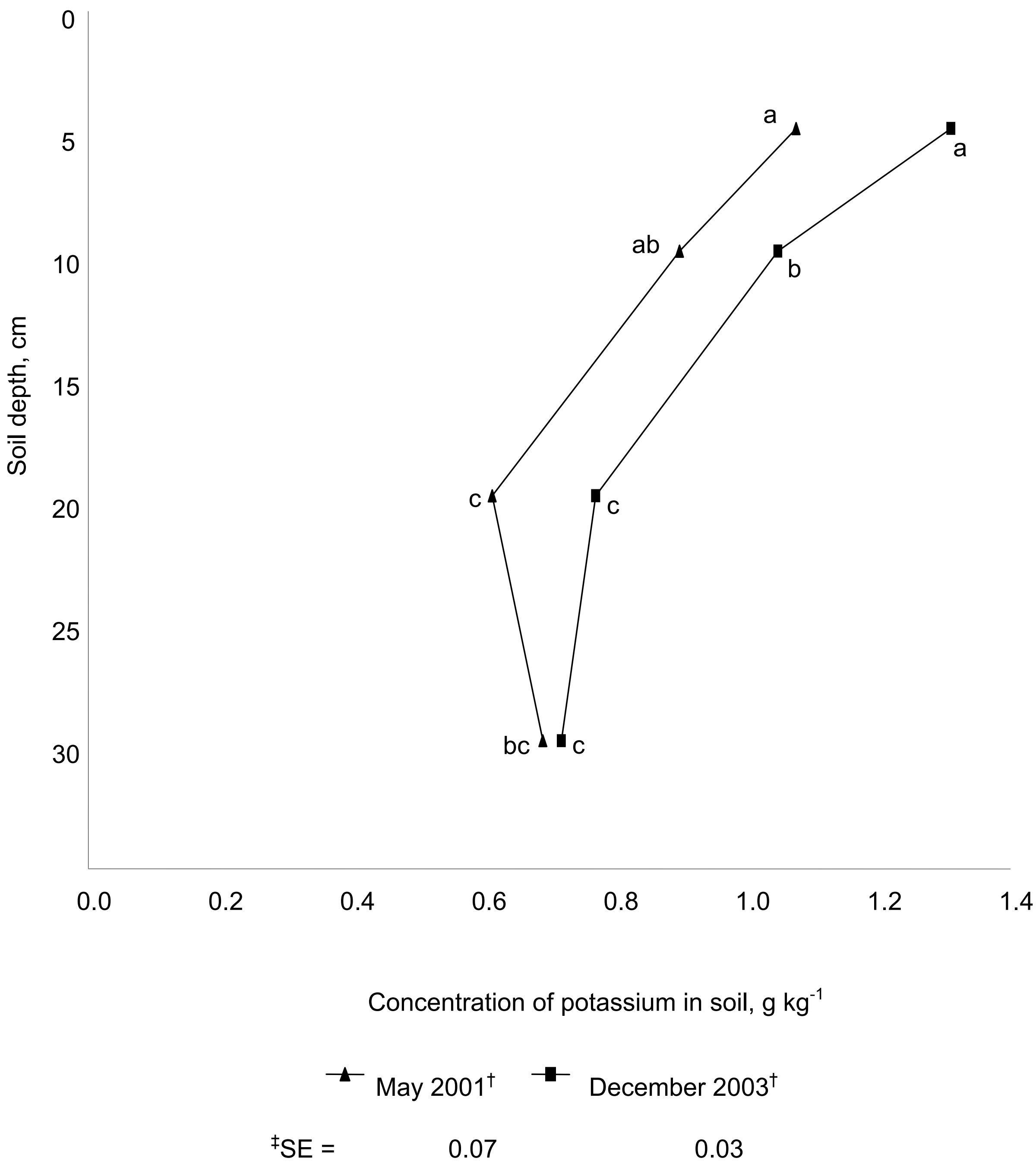

Fig. 2.13. Extractable soil potassium at different soil depths, averaged across a cotton monoculture and an integrated crop-livestock system that included WW-B. Dahl perennial pasture, a rye-cotton-wheat, and a wheat-fallow-rye rotation in May 2001 and December 2003 at New Deal TX.
[a,b] Means with the same letter within a year were not different ($P > 0.05$). † Date effect ($P < 0.05$). ‡ SE = Standard error of the mean.

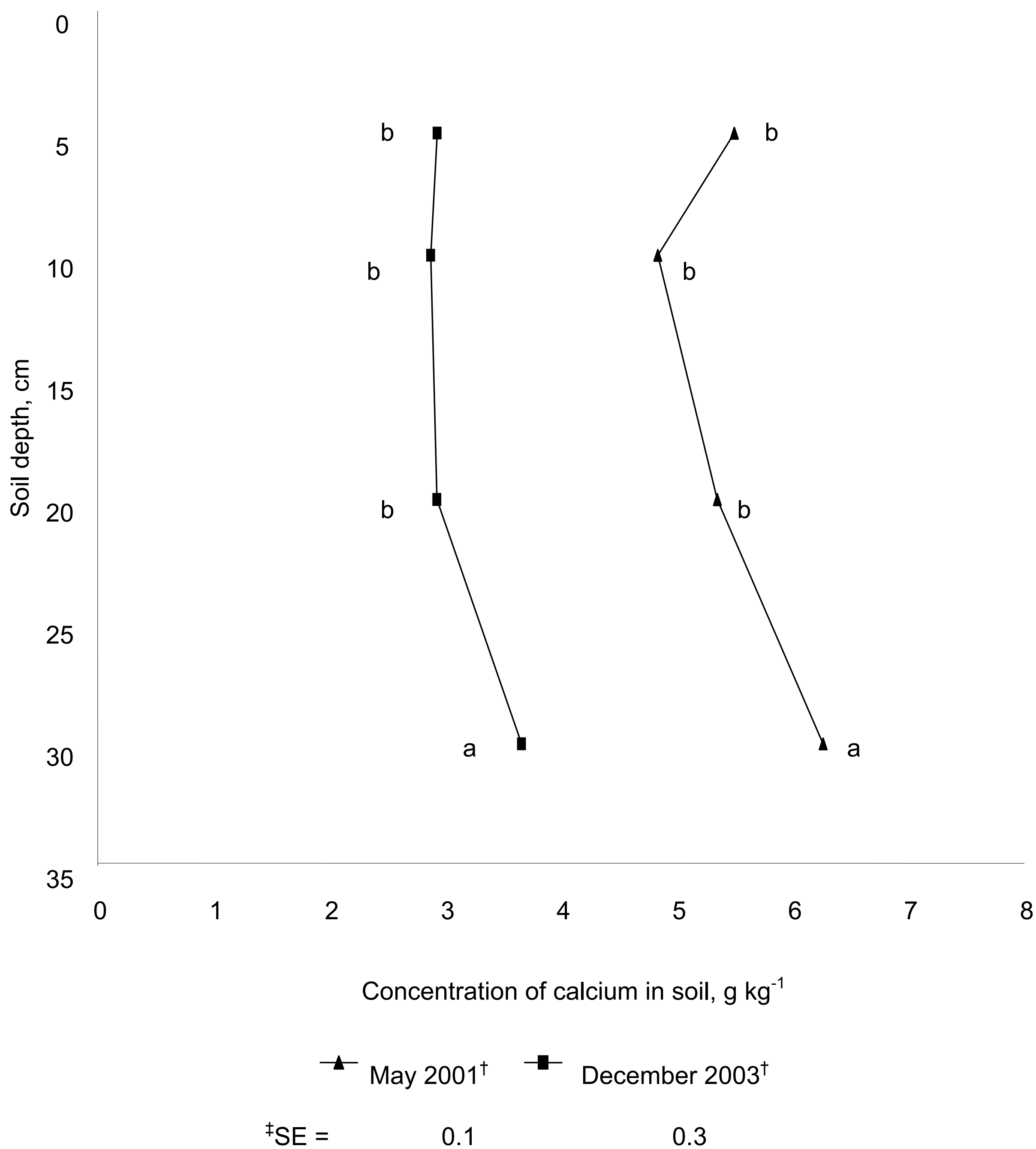

Fig. 2.14. Extractable soil calcium at different soil depths, averaged across a cotton monoculture and an integrated crop-livestock system that included WW-B. Dahl perennial pasture, a rye-cotton-wheat, and a wheat-fallow-rye rotation in May 2001 and December 2003 at New Deal TX.
[a,b] Means with the same letter within a year were not different ($P > 0.05$). † Date effect ($P < 0.05$). ‡ SE = Standard error of the mean.

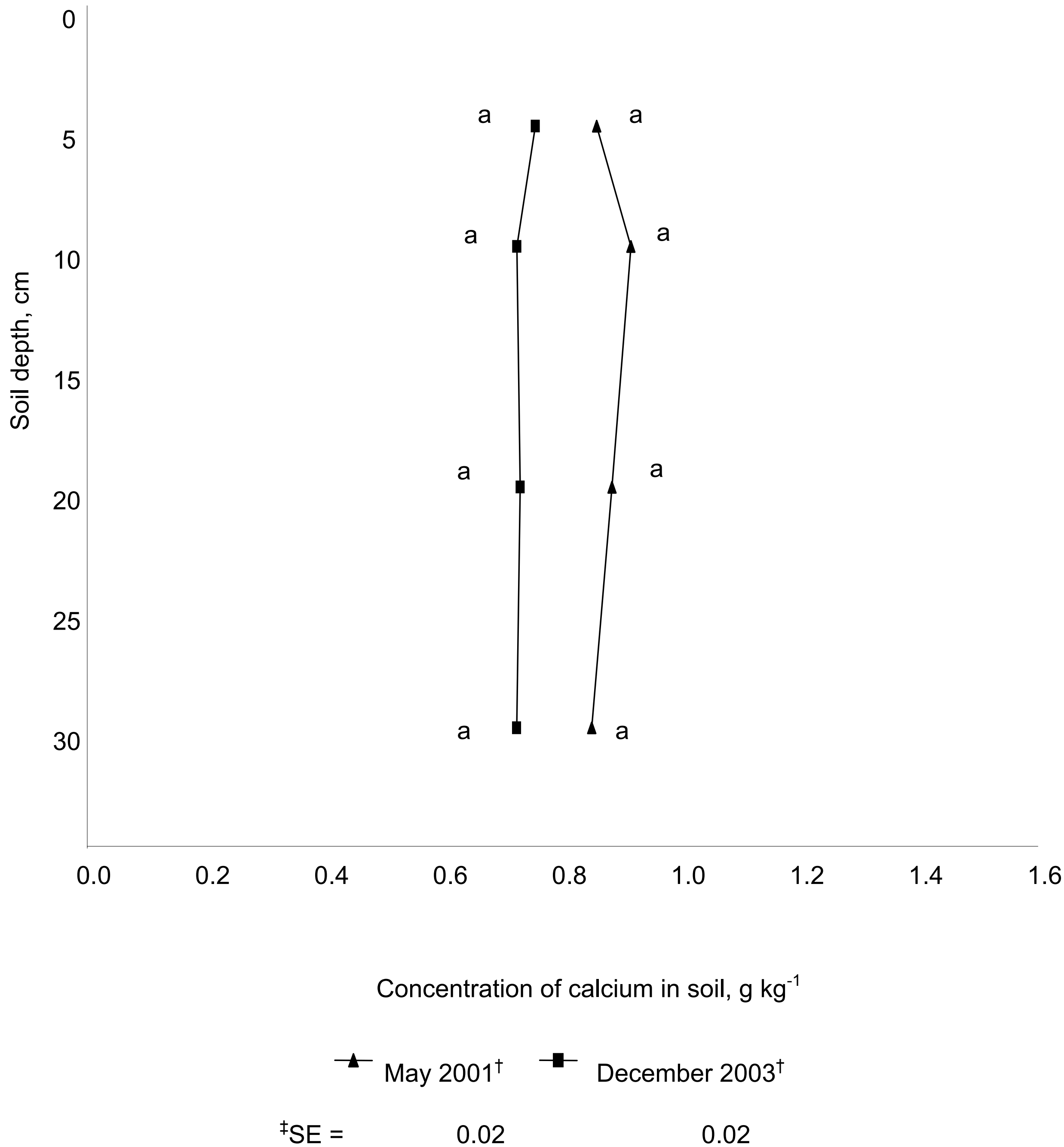

Fig. 2.15. Extractable soil magnesium at different soil depths, averaged across a cotton monoculture and an integrated crop-livestock system that included WW-B. Dahl perennial pasture, a rye-cotton-wheat, and a wheat-fallow-rye rotation in May 2001 and December 2003 at New Deal TX.
[a,b] Means with the same letter within a year were not different (P < 0.05). † Date effect (P < 0.05). ‡ SE = Standard error of the mean.

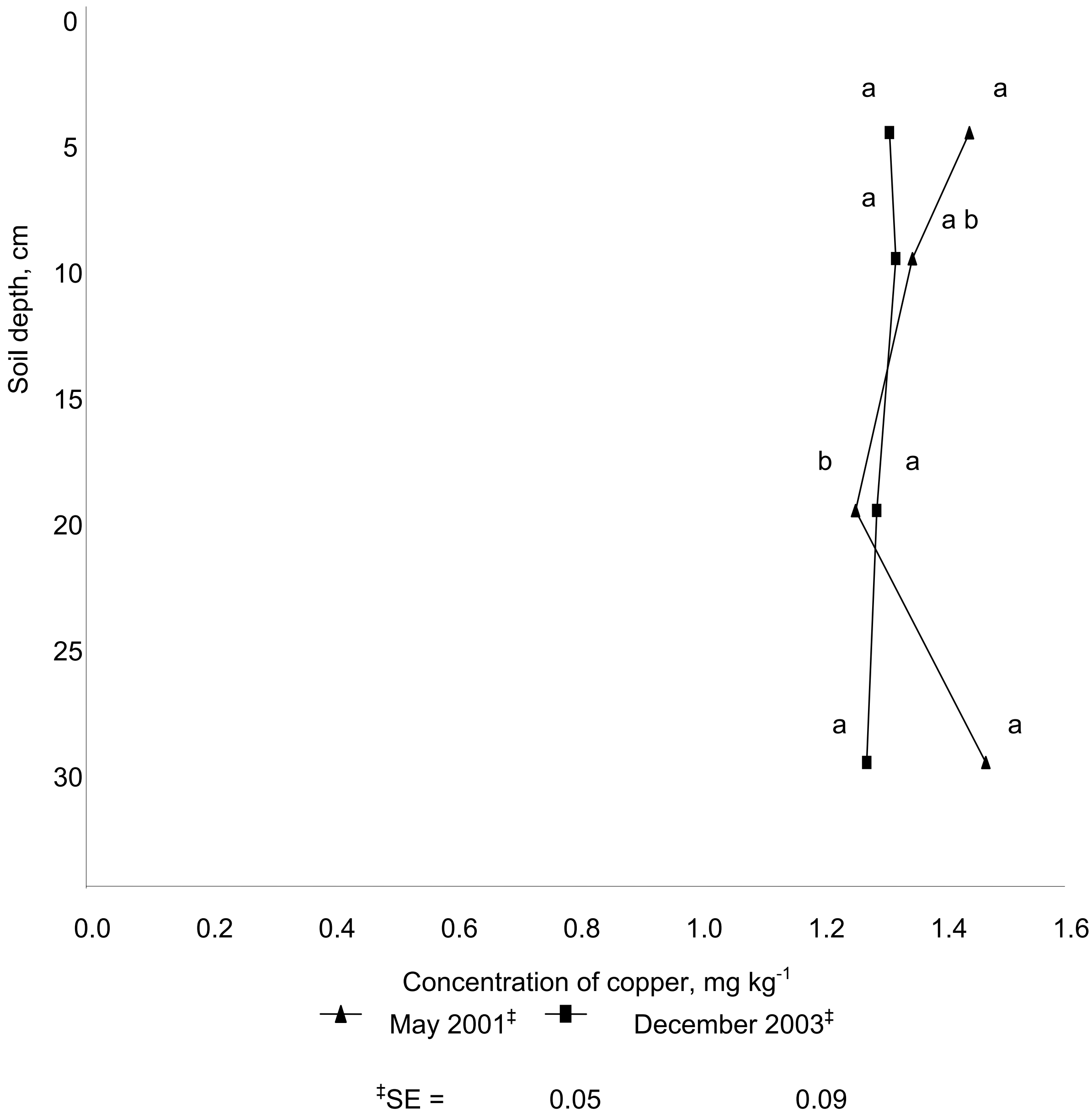

Fig. 2.16. Extractable soil copper at different soil depths, averaged across a cotton monoculture and an integrated crop-livestock system that included WW-B. Dahl perennial pasture, a rye-cotton-wheat, and a wheat-fallow-rye rotation in May 2001 and December 2003 at New Deal TX.
[a,b] Means with the same letter within a year were not different ($P < 0.05$). † Date effect ($P < 0.05$). ‡ SE = Standard error of the mean.

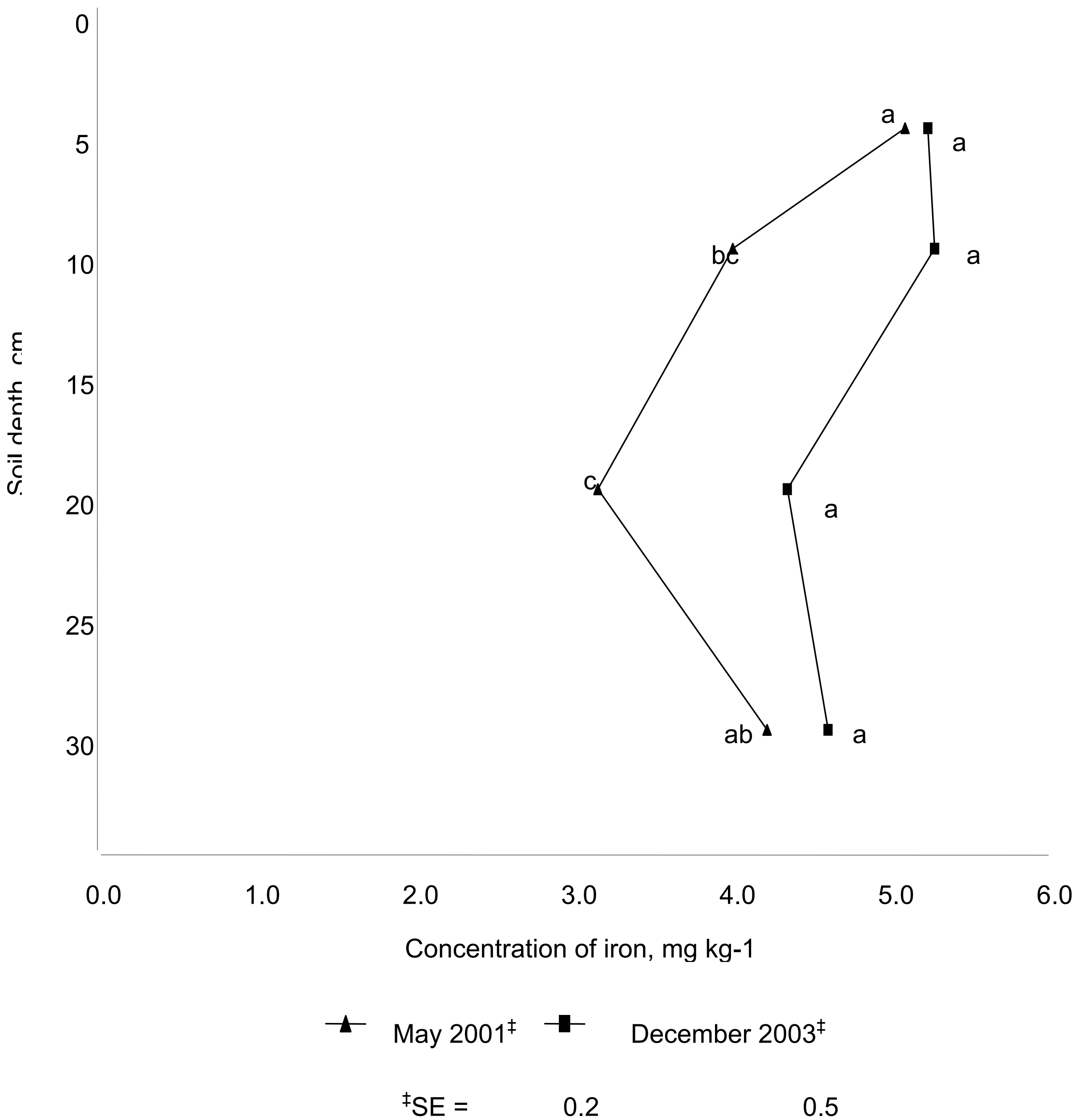

Fig. 2.17. Extractable soil iron at different soil depths, averaged across a cotton monoculture and an integrated crop-livestock system that included WW-B. Dahl perennial pasture, a rye-cotton-wheat, and a wheat-fallow-rye rotation in May 2001 and December 2003 at New Deal TX.

[a,b] Means with the same letter within a year were not different ($P < 0.05$). † Date effect ($P < 0.05$). ‡ SE = Standard error of the mean.

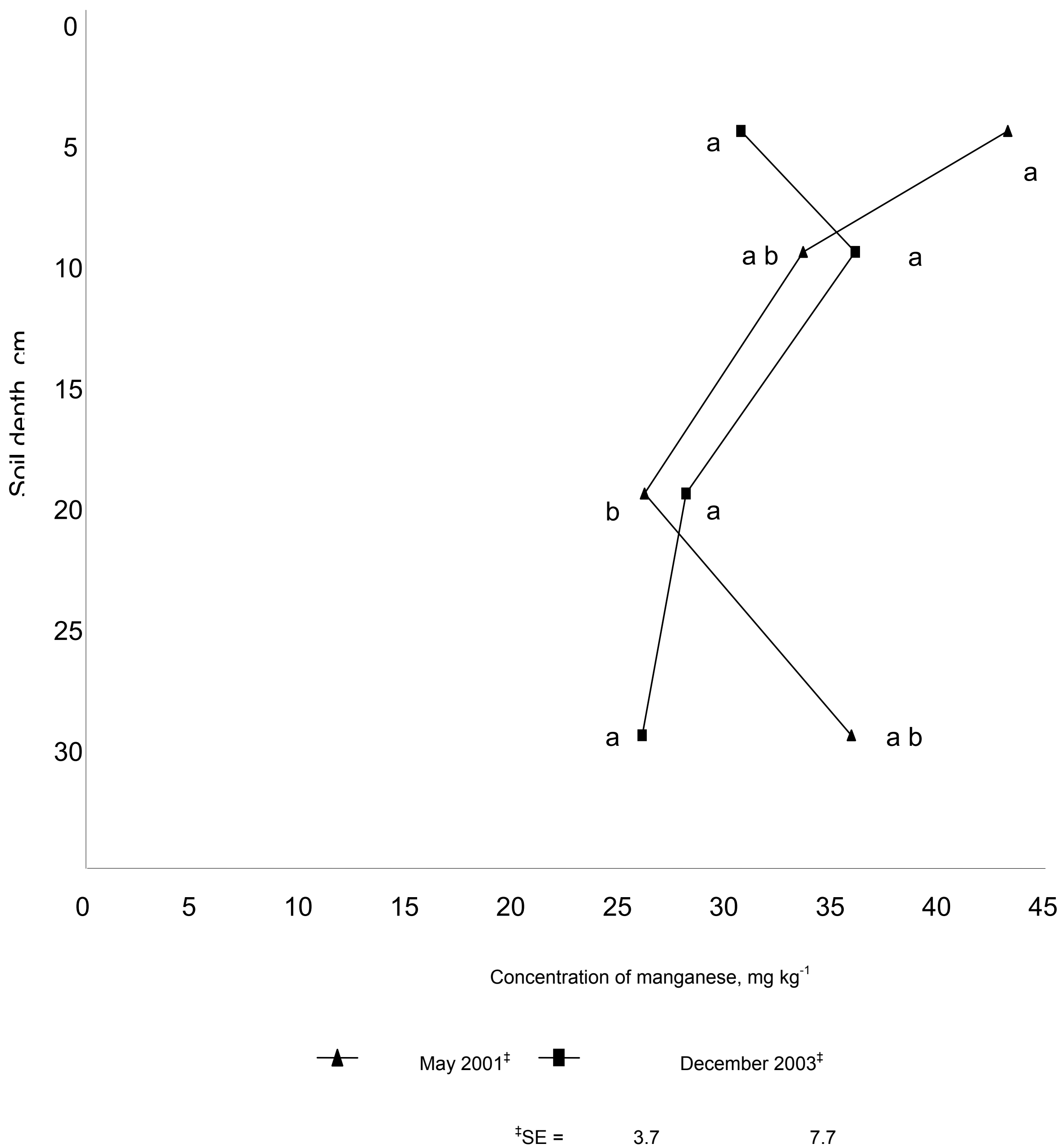

Fig. 2.18. Extractable soil manganese at different soil depths, averaged across a cotton monoculture and an integrated crop-livestock system that included WW-B. Dahl perennial pasture, a rye-cotton-wheat, and a wheat-fallow-rye rotation in May 2001 and December 2003 at New Deal TX.
[a,b] Means with the same letter within a year were not different ($P < 0.05$). † Date effect ($P < 0.05$). ‡ SE = Standard error of the mean.

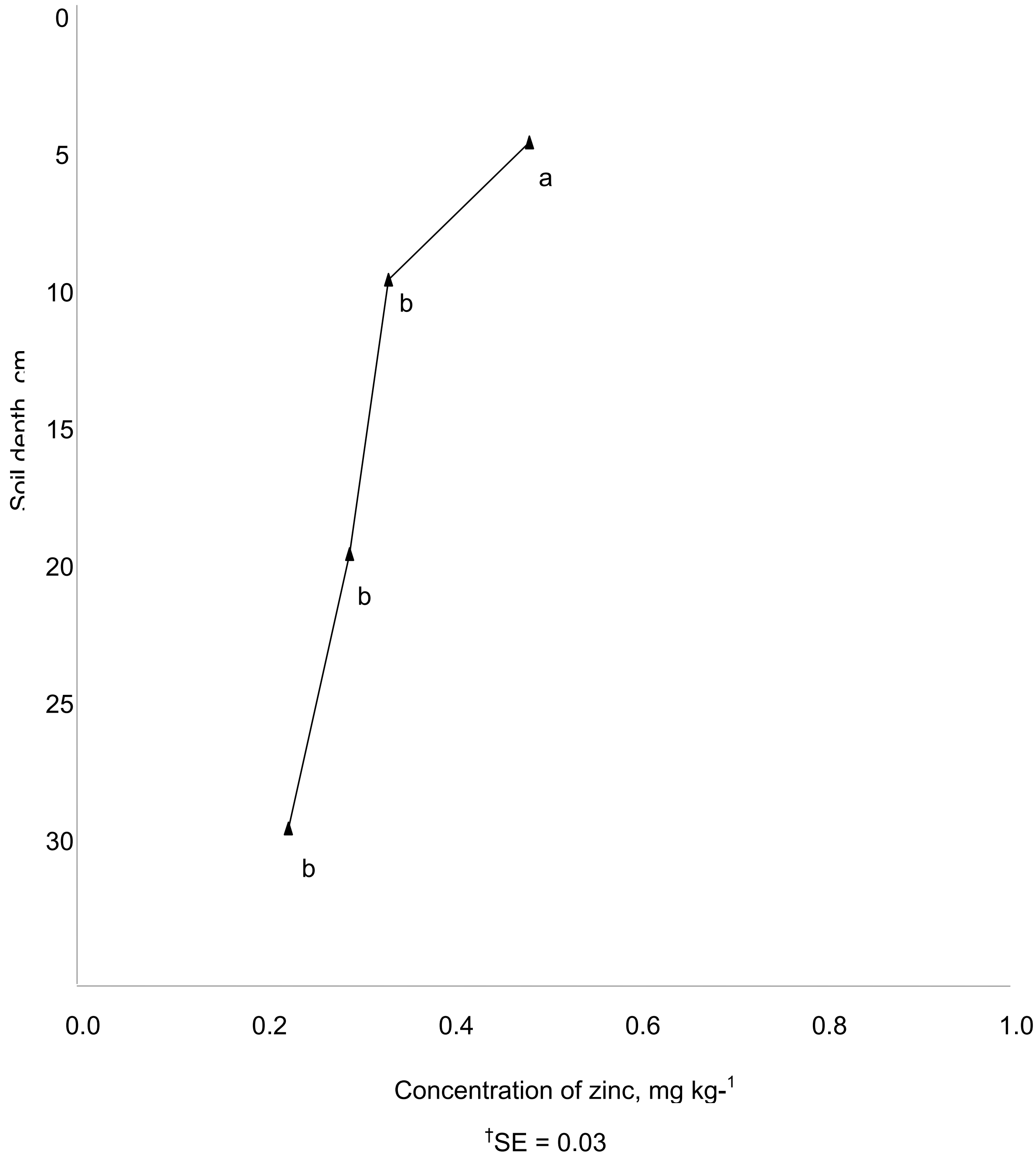

Fig. 2.19. Extractable soil zinc at different soil depths. averaged across a cotton monoculture and an integrated crop-livestock system that included WW-B. Dahl perennial pasture, a rye-cotton-wheat, and a wheat-fallow-rye rotation in May 2001 and December 2003 at New Deal TX.

[a,b] Means with the same letter within a year were not different ($P < 0.05$). † SE = Standard error of the mean.

Soil compaction

Effects of the cotton monoculture and the integrated crop-livestock system on soil compaction depended on sampling date (date by system component interaction; $P < 0.05$), thus, results for each system component at a given sampling date were analyzed separately. Grazing effect on soil compaction in the integrated system depended on the system component (system component by date interaction; ($P < 0.05$), thus, results for each component of the integrated system at a given sampling date were analyzed separately.

In February 2003, compaction in soils from the cotton monoculture was higher ($P < 0.05$) than the mean of soils from the integrated system components (Fig 2.20) and was also higher ($P < 0.05$) than the integrated system components individually. Compaction on soils from WW-B. Dahl was lower ($P < 0.05$) than the mean of rye-cotton-wheat and wheat-fallow-rye rotation. Compaction in soils from rye-cotton-wheat was higher ($P < 0.05$) from that in wheat-fallow-rye. In November 2003, this pattern had reversed and higher compaction was observed in WW-B. Dahl soils than in paddocks with the cotton-small grains rotations. Compaction was higher in the cotton monoculture than where cotton was planted in the integrated system. By November 2003, at the end of the growing season for cotton, compaction had declined in both, the cotton monoculture and cotton in the integrated system but remained higher ($P < 0.05$) in the cotton monoculture than for cotton in the integrated system at both sampling dates.

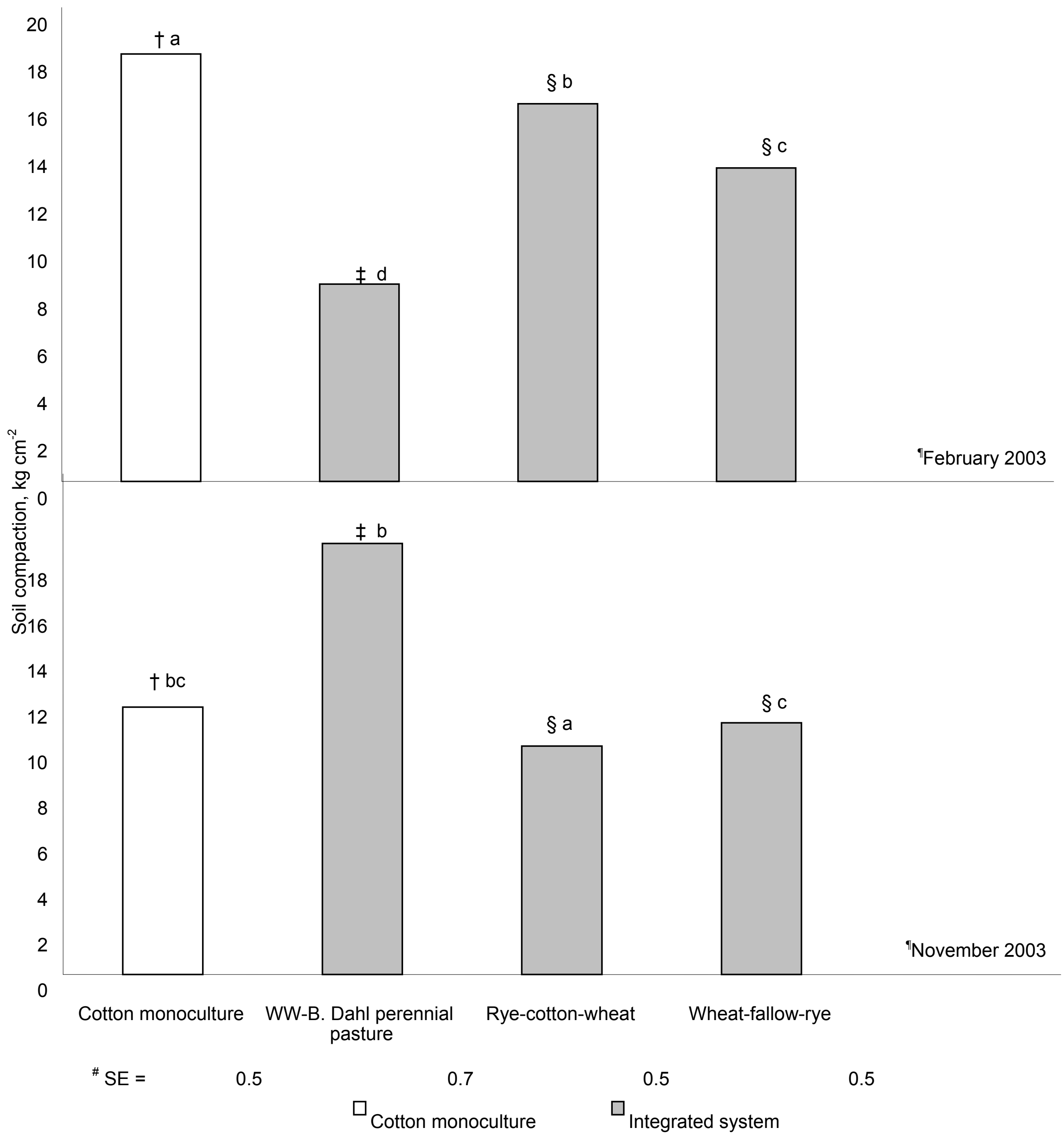

Fig. 2.20. Compaction of soils from a cotton monoculture and a crop-livestock system that included WW-B. Dahl perennial pasture, a rye-cotton-wheat and a wheat-fallow-rye rotation in 2003 at New Deal, TX. † Indicates difference ($P < 0.05$) between soils from the cotton monoculture and the mean of soils from the crop-forage-livestock system. ‡ Indicates differences ($P < 0.05$) between soils from the rye-cotton-wheat and wheat-fallow-rye rotation. § Indicate a date by system component interaction ($P < 0.05$). ¶ Indicates a date by system component interaction. #SE = standard error of the mean.

Experiment 2. Effect of grazing vs. no grazing
by steers on extractable soil minerals
and compaction

Extractable soil minerals

Extractable soil P and Cu in the surface 5 cm did not depend on sampling date and their results were analyzed across sampling dates (Table 2.3). Effect of grazing activity on extractable soil Fe in the surface 5 cm depended on sampling date (date by grazing interaction; $P < 0.05$; table 2.3), thus results for this mineral were analyzed separately at any given sampling date. Nitrogen as nitrate, K, Ca, Mg, Mn, and Zn, results were also analyzed independently at any sampling date, although the interaction of date by grazing was not significant ($P > 0.05$), but the interaction sampling date by system component was significant ($P < 0.05$; Table 2.4-2.5).

Grazing did not affect ($P > 0.05$) extractable P and Cu in the first 5 cm of soils in the alternative system. Soils where cattle had grazed each yr since 1999 did not differ ($P > 0.05$) from non-grazed soil in extractable NO_3^--N, K, Ca, Mg, and Fe in either May 2001 or December 2003 in the surface 5 cm. In May 2001, extractable Zn in the first 5 cm of soils of non-grazed areas of the integrated system was higher ($P < 0.05$) than in the first 5 cm of soils of grazed areas but no differences ($P > 0.05$) were observed in December 2003. No differences between grazed and non-grazed areas in extractable Mn existed in May 2001. By December 2003 extractable Mn was higher ($P < 0.05$) in grazed areas than in non-grazed areas of the rye-cotton-wheat-fallow rotation and lower ($P < 0.05$) in WW-B. Dahl grazed than in non-grazed areas.

Table 2.3. Extractable soil minerals on the first 5 cm of soils from an integrated crop-livestock system that included WW-B. Dahl perennial pasture, a rye-cotton-wheat and a wheat-fallow-rye rotation averaged across May 2001 and December 2003 at New Deal, TX.

	Forage						
	WW-B. Dahl perennial pasture		Rye		Wheat		SE[†]
	Treatment						
Mineral	Grazing	Non-grazing	Grazing	Non-grazing	Grazing	Non-grazing	
NO_3^--N, mg kg^{-1} [‡‡, §]	2.4	10.0	43.7	24.3	31.5	27.8	5.1
P, mg kg^{-1} [‡‡, #, ¶]	7.0	7.1	8.9	9.4	6.1	6.4	0.5
K, g kg^{-1} [‡‡, §, #]	1.1	1.0	1.3	2.0	1.2	1.1	0.1
Ca, g kg^{-1} [‡‡, §]	4.6	4.5	3.7	3.8	4.2	5.1	0.3
Mg, g kg^{-1} [‡‡, §, ‡]	0.8	0.9	0.9	0.8	0.8	0.9	0.03
Fe, mg kg^{-1} [††]	3.6	5.0	6.3	6.1	4.2	5.5	0.6
Cu, mg kg^{-1} [#]	1.2	1.2	1.6	1.4	1.2	1.3	0.1
Mn, mg kg^{-1} [§, #]	14.5	18.3	63.4	44.4	26.4	22.5	7.7
Zn, mg kg^{-1} [†, §, ‡,]	0.4**	0.8	0.5**	2.3	0.4**	1.4	0.3

[†] SE = standard error of the mean.
[‡] Indicates effect of grazing ($P < 0.05$) averaged over forage.
[§] Indicates interaction of forage*year ($P < 0.05$).
[#] Indicates effect of forage ($P < 0.05$).
[¶] Indicates interaction of forage*grazing*year ($P < 0.05$).
[††] Indicates effect of grazing*year ($P < 0.05$).
[‡‡] Indicates effect of year ($P < 0.05$).

Table 2.4. Extractable soil minerals on the first 5 cm of soils from an integrated crop-livestock system that included WW-B. Dahl perennial pasture, a rye-cotton-wheat and a wheat-fallow-rye rotation in May 2001 at New Deal, TX.

	Forage						
	WW-B. Dahl perennial pasture		Rye		Wheat		
	Treatment						
Mineral	Grazing	Non-grazing	Grazing	Non-grazing	Grazing	Non-grazing	SE†
NO_3^--N, mg kg^{-1} ‡	2.8	10.6	13.8	10.3	15.1	8.2	2.0
K, g kg^{-1}	1.1	1.0	1.0	1.0	1.1	1.0	0.1
Ca, g kg^{-1}	4.9	4.9	4.9	5.1	5.9	5.8	0.6
Mg, g kg^{-1}	0.9	1.0	1.0	0.9	0.8	0.8	0.06
Fe, mg kg^{-1} §	3.2	5.7	6.3	7.7	3.0	5.3	0.6
Mn, mg kg^{-1} §	13.4	19.5	74.9	67.3	14.0	21.3	7.1
Zn, mg kg^{-1} ‡, §, ¶	0.3*	0.7	0.6*	3.6	0.4*	0.6	0.4

† SE = standard error of the mean.
‡ Indicates effect of the interaction forage*grazing ($P < 0.05$).
§ Indicates effect of forage ($P < 0.05$).
# Indicates effect of grazing ($P < 0.05$) averaged over forage.
* Indicates differences between means ($P < 0.05$).

Table 2.5. Extractable soil minerals on the first 5 cm of soils from an integrated crop-livestock system that included WW-B. Dahl perennial pasture, a rye-cotton-wheat and a wheat-fallow-rye rotation averaged across in December 2003 at New Deal, TX.

	Forage						
	WW-B. Dahl perennial pasture		Rye		Wheat		
	Treatment						
Mineral	Grazing	Non-grazing	Grazing	Non-grazing	Grazing	Non-grazing	SE†
NO_3^--N, mg kg^{-1} ‡, §	2.1	9.3	73.6	38.3	48.0	47.3	6.0
K, g kg^{-1}	1.1	1.0	1.5	1.4	1.4	1.2	0.1
Ca, g kg^{-1}	4.3	4.0	2.4	2.5	2.5	4.5	0.7
Mg, g kg^{-1}	0.8	0.8	0.7	0.7	0.8	0.9	0.04
Fe, mg kg^{-1}	4.0	4.3	6.4	4.6	5.3	5.6	1.0
Mn, mg kg^{-1} #	15.5*	17.1	51.9	21.4	38.9	23.8	12.5
Zn, mg kg^{-1}	0.5	1.0	0.5	1.1	0.5	2.2	0.4

† SE = standard error of the mean.
‡ Indicates effect of the interaction forage*grazing (*P* < 0.05).
§ Indicates effect of forage (*P* < 0.05).
# Indicates effect of grazing (*P* < 0.05) averaged over forage.
* Indicates differences between means (*P* < 0.05).

Soil compaction

In February 2003, compaction in soils of the rye-cotton-wheat and wheat-fallow-rye rotations was similar ($P > 0.05$) in grazed and non-grazed areas (Fig. 2.21). Conversely, compaction in soils from WW-B. Dahl perennial pastures, was higher ($P < 0.05$) in grazed than in non-grazed areas. By June, July and November 2003 soil compaction in the rye-cotton-wheat rotation was higher ($P < 0.05$) in grazed than in non-grazed areas. Similar pattern was observed in soils from wheat-fallow-rye in June and July 2003, but, the opposite occurred In November 2003. Compaction of soils from WW-B. Dahl did not differ ($P > 0.05$) between grazed and non-grazed areas in June, but by July and November, grazed areas showed higher ($P < 0.05$) soil compaction than non-grazed areas.

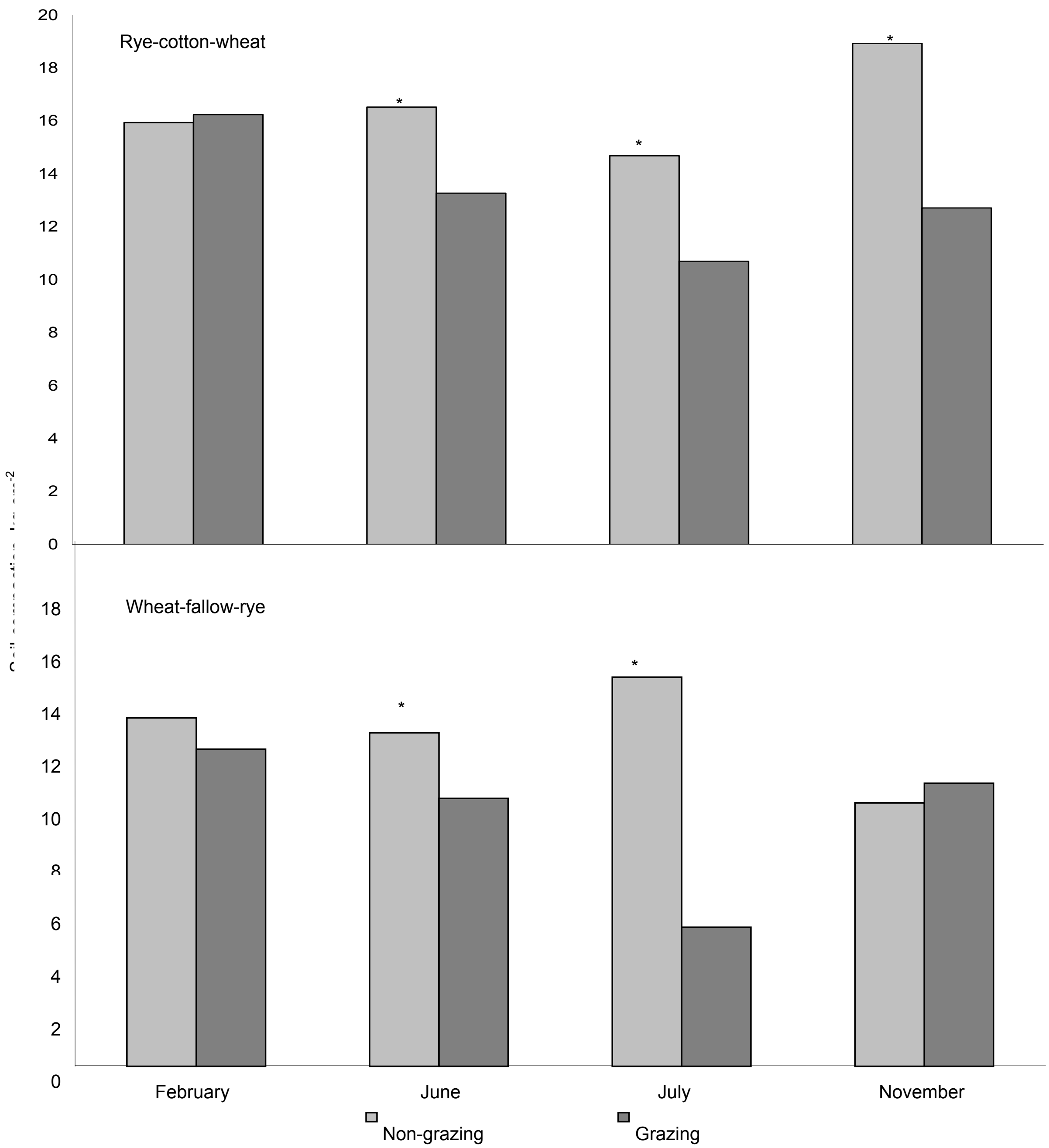

Fig. 2.21. Compaction of soils from grazing and non-grazing areas of a rye-cotton-wheat and a wheat-fallow-rye rotation in 2003 at New Deal, TX. * Indicates difference ($P < 0.05$) between means.

Experiment 3. Effect of three grazing intervals on

WW-B. Dahl on extractable soil minerals

and compaction

Extractable soil minerals

Extractable soil NO_3^--N, P, K, Ca, Mg, Na, Cu, Fe, Mn, and Zn results did not depend on sampling date (sampling date by grazing and sampling date by system component not significant; *P* > 0.05; table 2.6) thus, their results were analyzed across sampling dates.

Of all minerals investigated, only extractable soil Zn and Mg were affected (P < 0.05) by grazing length. Extractable Zn and Mg in soils from non-grazed areas were higher (*P* < 0.05) than the mean of soils from grazed areas but grazed areas did not differ (*P* > 0.05) in either one of them.

Soil compaction

Grazing effect on soil compaction was dependent on sampling year (year by date interaction; *P* < 0.05), thus, results for each sampling year were analyzed separately. In June 2002, compaction in soils from non-grazed areas was lower (P < 0.05) than the mean of soils from grazed areas (Fig 2.22). Compaction in soils from short-term grazing period was higher (P < 0.05) than compaction in soils from long-term grazing period. In July 2002, compaction in soils from non-grazed areas was higher (P < 0.05) than the mean of soils from grazed areas. Compaction in soils from short grazing period was similar (P > 0.05) to compaction in soils from long grazing period. In June 2003, compaction in soils from non-grazed areas was lower (P > 0.05) than the mean of soils from grazed areas. Compaction in soils from short-term grazing period was higher (P < 0.05) than compaction in soils from long-term grazing period. In July 2003, compaction in soils from non-grazed areas was lower (P < 0.05) than the mean of soils from grazed areas. Compaction in soils from short-term grazing period was lower (P > 0.05) than compaction in soils from long-term grazing period. In February 2003, compaction in soils from non-grazed areas was higher (P < 0.05) than the mean of soils from grazed areas. Compaction in soils from short-term grazing period was higher (P < 0.05) than compaction in soils from long-term grazing period. In November 2003, compaction in soils from non-grazed areas was lower (P < 0.05) than the mean of soils from grazed areas. Compaction in soils from short-term grazing period was similar (P > 0.05) to compaction in soils from long-term grazing period.

Table 2.6. Extractable soil minerals on the first 5 cm of soils from a WW-B. Dahl perennial pasture averaged across May 2001 and Dec 2003 at New Deal, TX.

Mineral	Grazing period			
	Non-grazing	Short term	Long term	SE†
NO_3^--N, mg kg^{-1}	10.0	5.9	2.4	4.3
P, mg kg^{-1} ‡	7.1	7.3	7.0	0.4
K, g kg^{-1}	1.0	1.0	1.1	0.05
Ca, g kg^{-1} ‡,	4.5	3.8	4.6	0.1
Mg, g kg^{-1} ‡, §	0.9	0.8	0.8	0.03
Na, mg kg^{-1}	68.3	49.4	74.8	6.6
Cu, mg kg^{-1}	1.2	1.3	1.2	0.0
Fe, mg kg^{-1}	5.0	3.8	3.6	0.4
Mn, mg kg^{-1}	18.3	15.2	14.5	2.0
Zn, mg kg^{-1} §, ¶	0.8	0.5	0.4	0.1

† SE = standard error of the mean.
‡ Indicates effect of year ($P < 0.05$).
§ Indicates effect of grazing ($P < 0.05$).
¶ Indicates differences ($P < 0.05$) between the soils from non-grazing areas and the mean of soils from grazing areas.

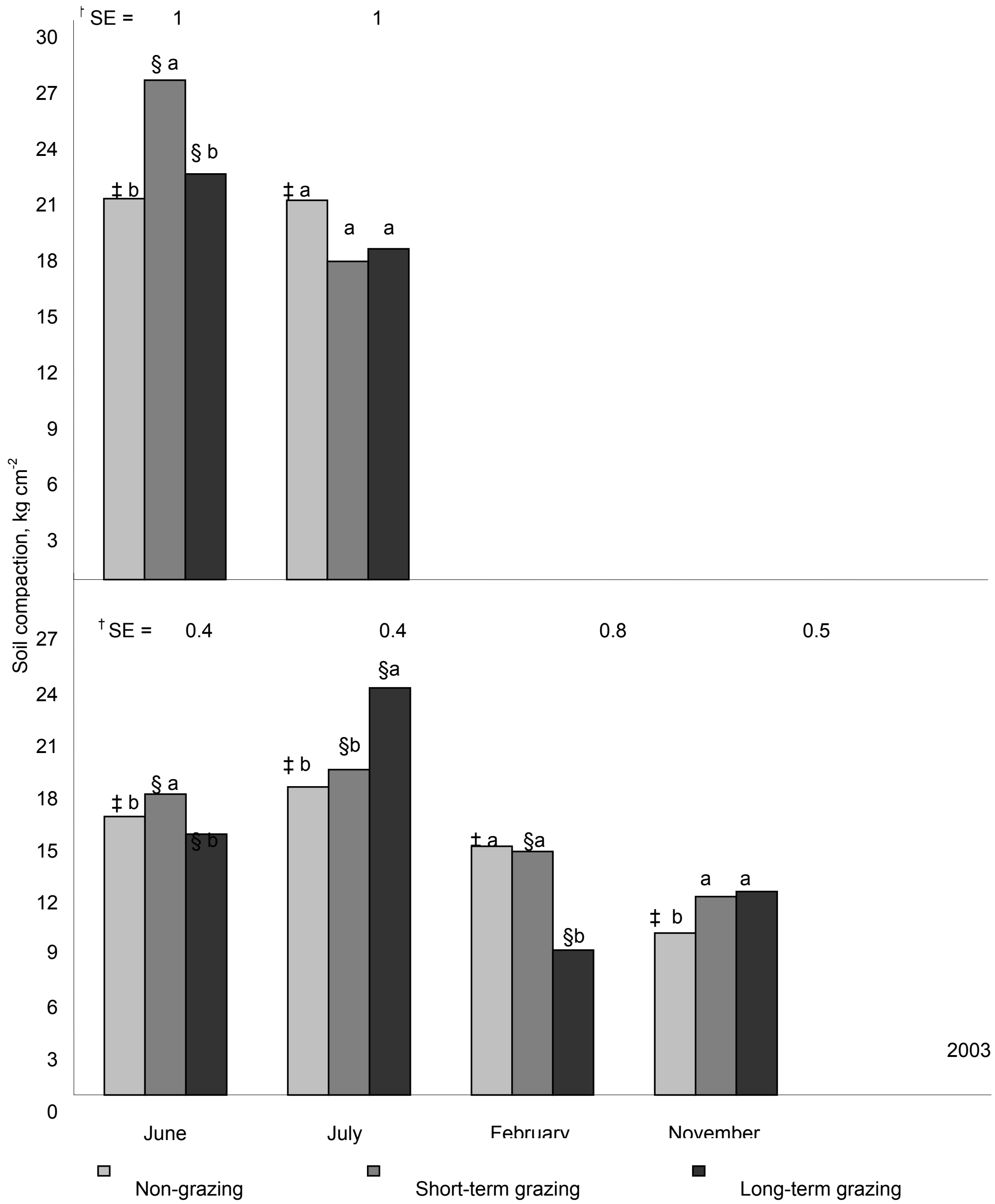

Fig. 2.22. Compaction of soils from a WW-B. Dahl perennial pasture grazed at different intervals in 2002 and 2003 at New Deal, TX.
† SE = standard error of the mean. ‡ Indicates differences (P < 0.05) between soils from the non-grazed areas the mean of soils from the grazed areas. § Indicates differences (P < 0.05) between soils from the rye-cotton-wheat and wheat-fallow-rye rotation. [a,b] Means with different letter within a date are different (P < 0.05).

Discussion

Extractable soil minerals

In May 2001, NO_3^- -N differences between soils of the cotton monoculture and the integrated crop-livestock systems were due to NO_3^- -N levels found in soils of the WW-B. Dahl pastures. Furthermore, NO_3^- -N in soils was similar in areas where cotton was planted at same point during the growing season. This pattern was also noticed in December 2003, although differences between systems did not hold. The high NO_3^- -N levels found in the rye-cotton soil were due to the application of N fertilizer in this area in July, as part of the cotton management strategy and again in September in order to establish the wheat for grazing the next yr, while cotton monoculture and WW-B. Dahl pastures were fertilized in July and August respectively. When averaged across system components, the higher level of NO_3^- -N in December 2003 can also be attributed to the N fertilizer applied in the rye-cotton-wheat areas only two mo prior to the sampling date. In WW-B. Dahl pastures, NO_3^- -N levels were maintained consistently within the profile, while in soils where cotton was present, NO_3^- -N levels decreased in the first 20 cm. This effect was more marked in the rotation areas of the integrated system than in the cotton monoculture in December 2003. When the grazing effect was analyzed in the first 5 cm of soils, NO_3^- -N levels were not affected by grazing, although, the effect of system component and year was still present. A further analysis of the length of grazing on the first 5 cm of soils of WW-B. Dahl pastures, showed no effect of length of grazing in NO_3^- -N levels. Whitehead (1995) reported that NO_3^- -N is lower in grassland than in similar soils under cultivation, likely due to a decrease in the nitrification process beneath a grass sward, related to the release of organic compounds by grass.

Phosphorus levels in soils from all areas of the cotton monoculture and the integrated system observed in this research were among the levels indicated as normal in the literature (Havlin *et al*., 1999; Pierzynski *et al*., 2000), although in 2001, the P levels were in the lower range. In 2003, it was necessary to apply P fertilizer because the low levels of this mineral in the soil were limiting the growth of both forages and cotton. Levels of P increased in 2003 after the application of P fertilizer in June of that yr because water-soluble P fertilizer applied to soil readily dissolves and increases the concentration of P in the soil solution (Havlin *et al*., 1999). However, the increase of P levels in soils of cotton monoculture was enough to overturn the 2001 situation of P levels being lower in areas cropped exclusively with cotton. This same effect was observed in wheat-fallow-rye areas, where the increase on soil P in 2003 reached similar levels to P in soils from the rye-cotton-wheat rotation. Proportionally, increases in soil P in all three components of the integrated system were similar, thus, maintaining the pattern first noticed in 2001. Phosphorus concentrated in the surface 5 cm and declined with depth but stayed constant throughout the profile to 30 cm; this pattern was similar for both yr analyzed. Fertilizer was applied through the sub-surface system, thus, it was expected that higher levels of P were to be found at deeper soil zones. When the effect of grazing on P was analyzed in the first 5 cm of soils of the integrated system, there were no differences in P levels associated to grazing. Moreover, when different grazing intervals on the WW-B. Dahl perennial pastures were also analyzed, P did not respond to length of grazing. Beef cattle manure contains about 0.7 to 1.2% of P on a dry matter basis (Havlin *et al*., 1999) which was expected to increase the levels of P in the grazed areas of the integrated system, considering that grazing had been occurring for 3 and 6 years before the sampling of 2001 and 2003, respectively. However, there are several factors that affect the rate of conversion of organic into inorganic P forms. In some cases, fresh plant residues may quickly release P into the soil solution while animal manure generally acts as a long-term, slow-release source of P (Pierzynski *et al*., 2000). In the present research no-till practices were used, leaving in the field a great amount of plant residue, which can explain the fact of P being accumulated in the surface instead than deeper in the profile where the fertilizer was applied. This also can explain the apparent lack of effect of manure in the P levels. Although 6 yr can be considered a long time, it is likely that is not long enough to start showing effects of manure in P levels. In the case of the grazing intervals of WW-B. Dahl, this was more evident, because grazing intervals were carried on only for 3 years.

Levels of K found were very high and, therefore, not limiting for plant growth. Fine-textured soils formed from rocks high in K-bearing minerals are high in K. The lack of differences among systems and system components in May 2001 can be explained by the fact that soils in the research site are naturally high in K. Philipp (2005) reported K levels in the New Deal, TX field laboratory of 600 mg kg^{-1}. Pullman soils have a mixed clay mineralogy including a large proportion of montmorillonite

(Evett *et al*., 2002; Unger, 1999). Soils containing vermiculite, montmorillonite or illite (2:1 clays), have more K than soils containing predominantly kaolinite (1:1 clay), which is highly weathered and very low in K (Havlin *et al*., 1999). However, in December 2003, K decreased in soils from the WW-B. Dahl which caused significant differences in K levels of these soils with respect of K levels in soils from the rye-cotton-wheat-fallow rotation. Decline of K within the soil profile could also be related to the high clay content of the soil; in fine textured soils, K leaching losses are small (Havlin *et al*., 1999). As in the case of N and P, grazing and grazing length did not affect K level in the soil.

Soil Ca and Mg levels were high in both systems and in both yr. Philipp (2005) reported average Ca and Mg levels for the research site of 3050 mg kg^{-1} and 600 mg kg^{-1}, respectively. Calcium is high in fine-textured soils formed from rocks high in Ca, and in soils of arid regions because of low rainfall (Havlin *et al*., 1999). Calcite $CaCO_3$ is the dominant source of Ca in semi-arid and arid regions; dolomite [$CaMg(CO_3)_2$] may also be present in soils of these regions which accounts for high levels of Mg in the original material from which soil is formed. Montmorillonite and other 2:1 clays are also a constant source of Mg in the soil. Calcium levels in 2001 were similar between systems with a slightly lower Ca level in soils from the rye-cotton-wheat rotation, which was not lower enough to produce differences between systems or between WW-B. Dahl and the average of both rotations. By 2003 Ca levels decreased in soils from the cotton monoculture and from all components of the integrated system. This decrease was greater in soils where cotton was planted at some point during the growing season which caused differences between cotton monoculture and the integrated system and between WW-B. Dahl and the average of both rotations. Results suggest that the rate at which Ca in soil is being used by the crops is faster than the rate at which it is replenished from the parental material. Furthermore, soils from WW-B. Dahl had a lower level of Ca than cotton, rye, and wheat which suggest a higher uptake of Ca by WW-B. Dahl than by annual crops. Levels of Mg exhibited the same pattern as Ca, although the effect of cotton in the rotation on Mg levels was less marked. Calcium accumulation at deeper intervals is likely due to the high Ca content of the parental material that originates the soils in this region. The constant level of Mg within the profile suggest that the origin of Mg in the soils studied could be due most likely to the weathering of 2:1 clays, which is a slow process, and not to the presence of high amounts of dolomitic rocks. As in the case of the minerals previously discussed there is not evidence of the effect of grazing and grazing length on soil Ca and Mg levels.

Extractable Na was analyzed only in the WW-B. Dahl component of the integrated system. Levels of Na are very low and were not affected by grazing or length of grazing. From the results obtained the WW-B. Dahl there was no evidence that suggest a problem of Na accumulation in the soil.

Extractable Cu, Fe, and Mn had a similar patterns in the two years when the soils were sampled. Soils where cotton was present in 2001 (cotton monoculture and rye-cotton-wheat rotation) exhibited higher levels of Cu, Fe, and Mn, than soils from WW-B. Dahl pastures and wheat-fallow-rye rotation. Although, only levels of Cu and Fe were lower in the rye-cotton-wheat rotation than in the cotton monoculture. Lower levels of Cu, Fe and Mn in soils of two of the integrated system components caused differences between this integrated system and the cotton monoculture. Although, there was no difference in levels of these mineral in soils from WW-B. Dahl and wheat-fallow-rye rotation, higher levels of Cu, Fe, and Mn in rye-cotton-wheat were enough to produce differences between soils from WW-B. Dahl and the rye-cotton-wheat-fallow rotation. By 2003, differences in Cu, Fe and Mn between soils of the cotton monoculture and the integrated system and among soils of the integrated system components disappeared, Although, the pattern that caused this lack of differences was similar for al three minerals. Levels of Cu, Fe and Mn decreased in the cotton monoculture and rye-cotton-wheat rotation and increased in WW-B. Dahl and wheat-fallow-rye rotation. However, this increase-decrease pattern produced an overall decrease in levels of Cu, Fe and Mn, in 2003 with respect to their levels in 2001. When analyzed by depth Cu, Fe and Mn variation pattern was similar, although differed by year. In 2001, levels of Cu, Fe, and Mn were constant to 30 cm while in 2003 these minerals were higher at the surface, with a decrease in the middle depths and an increase again at 30 cm.

Extractable Zn was also analyzed in the current research, but it did not followed the pattern of the other trace minerals which was not expected, in general, there is a tendency in the literature to reference results and occurrences of Cu, Fe, Mn, and Zn together, but in our case, Zn results were different from the other three minerals. Level of Zn in soils from both the cotton monoculture and the integrated system as well as its occurrence through the profile were consistently maintained for 2001 and 2003.

Similarly to NO_3^- -N, P, Ca and Mg, Cu and Fe did not respond to grazing or grazing length. However, the effect of grazing on Mn level was noticeable by 2003, although, length of grazing of WW-B. Dahl did not change Mn levels. However, the pattern observed in Mn levels varying accordingly to the integrated system component analyzed still hold; the effect of grazing in soil Mn was different depending on which forage was grazed. Levels of Mn in non-grazed soils from WW-B. Dahl and wheat-fallow-rye rotation are lower than levels on grazed soils, while for the case of the rye-cotton-wheat rotation the opposite occurs. Grazing affected Zn level in the soil, although, short and long term grazing intervals in the WW-B. Dahl component did not affect Zn soil levels differently. Levels of Zn were consistently higher in non-grazed than grazed areas regardless the integrated system component analyzed. It seems that in the case of Zn and to a lesser extent Mn, 6 yr of grazing is enough to produce noticeable changes in levels of these two minerals. Our results support the idea that the rates at which minerals attain equilibrium in the soil vary from a few hours to years and for some mineral equilibrium is never reached (Lindsay, 1991).

In general, soils vary widely in their micronutrient content and in their ability to supply micronutrients in quantities sufficient for optimal crop growth (Havlin, 1999). Original geologic substrate and subsequent geochemical and pedogenic regimes determine total levels of micronutrients in soils. Total levels are rarely indicative of plant availability because availability depends on soil pH, organic matter content, adsorptive surfaces, and other physical, chemical, and biological conditions in the rhizosphere (White and Zasoski, 1999). The ability of soils to provide nutrients, especially micronutrients, required by plants is a chemical soil property, thus, soil fertility variations can best be characterized through chemical examination of the soil (Sims and Johnson, 1991; Harter, 1991). Furthermore, availability of micronutrients to plants is often poorly related to the total quantity of the particular element in the soil Changes in the environment often have a greater effect on micronutrient than on macronutrient nutrition of plants (Moraghan and Mascagni, 1991). Mineral determination in the current research was done as a first step to understand how minerals vary in the soil. Sampling strategy was limited to only two dates, thus, results were punctual and cannot be thoroughly related. Furthermore, no other factors associated to mineral cycles and behavior in soil were either estimated or recorded, such as organic matter content, type and amount of textural particles, type of parent rock and soil temperature, among others.

Soil compaction

In February 2003, compaction readings were taken immediately before the starting of the grazing of dormant WW-B. Dahl. This point was considered the beginning of the grazing season for that yr. Results obtained can be explained based on the differences of timing and type of management practices for each system and for each component of the integrated system. In this month, cotton monoculture soils were more compacted than the soils from the integrated system, but were also more compacted than each component of the integrated system. Rye-cotton-wheat rotation had the highest compaction among the integrated system components, although it was lower than compaction in the cotton monoculture. Paddocks with cotton in that particular yr (monoculture and in the rye rotation) were harvested in November of 2002 to end the 2002 growing season, thus, the effect of the harvesting machinery passing in those paddocks on soil compaction was still reflected in February 2003; furthermore, wheat for the wheat-fallow-rye rotation of 2003 was planted into the rye-cotton-wheat paddocks also in November 2002. Harvest of 2002 WW-B. Dahl occurred in mid-October, and planting of rye for the rye-cotton-wheat of 2003 in the wheat paddocks occurred in September 2002. Results suggest that the difference of 1.5 months on machinery use is enough to modify compaction. This idea is reinforced by the results obtained for the same areas in November 2003. At this point in time, WW-B. Dahl had the highest soil compaction, partly because compaction readings were taken in early November, just after seed harvest, but before cotton harvest, thus, cotton monoculture and rye-cotton-wheat and wheat-fallow-rye rotations exhibited lower soil compaction. Additionally, WW-B Dahl was grazed by 60 d from the end of May to mid-July, while the small grains were grazed earlier and for a shorter time. The effect of harvesting WW-B. Dahl in November plus the effect of summer grazing was enough to drive changes on the whole pattern observed in February at the beginning of the grazing season. Furthermore, differences between the small grains rotations were due to the fact that by November 2003 rye for the 2004 season had already been planted in the wheat-fallow-rye paddocks.

When the effect of grazing in the integrated system was investigated, compaction readings were taken more frequently. As a result of the increase in time-points analyzed not only the grazing effect was evident but also differences among integrated system components were better explained. In February 2003, soil compaction in the small grain rotations was not different among grazed and non-grazed areas, however, in WW-B. Dahl pastures, non-grazed areas were more compact than grazed areas, although by June, at the end of the short-term grazing period, soil compaction in WW-B. Dahl grazed areas increased to the point that compaction was similar between grazed and non-grazed areas. Also by June, grazing season in the small grains had ended and the effect of grazing was noted. In both rye-cotton-wheat and wheat-fallow-rye grazed areas were more compacted than non-grazed areas. By July, the end of the long-term grazing period in the WW-B. Dahl pastures, the effect of grazing in soil compaction was evident. Grazed areas had higher compaction than non-grazed areas. In the small grains the grazing effect persisted and was noticeable independently from additional management practices required to complete the rotations. Rye-cotton-wheat was in the cotton phase and wheat-fallow-rye rotation was in the fallow stage, and although at this point the non-grazed areas underwent the same conditions than grazed areas in both rotations the grazing effect was still noted. Previously grazed areas showed higher compaction than previously non-grazed areas. By November, the effect of grazing on soil compaction in soils from WW-B. Dahl and rye-cotton-wheat rotation was still present. However, the grazing effect disappeared in the wheat-fallow-rye.

Additionally, soil compaction was analyzed also at the end of the short-term and long-term grazing periods in WW-B. Dahl perennial pastures. The pattern observed in 2003 in June was also observed in 2002; however, soil compaction pattern in July 2002 was different of that observed in July 2003.

Conclusions

Minerals in general were present within the normal ranges needed for plant production, N and P being the exception to the rule, and for which fertilization occurred and influenced their concentrations in soils. Mineral levels were associated to the soil type more than the productive system established or management practices developed. Although some differences between the cotton monoculture and the integrated system occurred, there was not enough evidence to suggest that the system was the cause of those differences.

Mineral determination in the current research was done as a first step to understand how minerals vary in the soil. Sampling strategy was limited to only two dates, thus, results were punctual and cannot be thoroughly related. Furthermore, organic matter content, type and amount of textural particles, type of parent rock and soil temperature, among others factors associated to mineral cycles and behavior in soil were neither estimated nor recorded. Further research would need the estimation and recording of those associated factors to fully explain results.

Levels of Na obtained in soils of WW-B. Dahl pastures suggest that after 6 yr of the project Na accumulation in soil is not a problem.

Variations on mineral levels throughout the soil profile found in our research followed the distribution expected for each mineral studied.

In general, our results did not provide enough evidence that mineral levels in the soil change over periods of 3 to 6 yr. However, Mn and Zn started to show evidence of variation due to grazing. Furthermore, changes in levels of Zn were consistently observed across all grazed components of the integrated system.

Soil compaction results obtained are a combination of factors in each one of the systems analyzed. Grazing plays a very important role on soil compaction, regardless the integrated system component analyzed.

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CHAPTER III

EFFECT OF DEFOLIATION STRATEGIES ON BIOMASS YIELD, BOTANICAL COMPOSITION, FORAGE QUALITY AND MINERAL CONCENTRATION OF WW-B. DAHL IN AN INTEGRATED CROP-LIVESTOCK SYSTEM ON THE TEXAS HIGH PLAINS

Abstract

WW-B. Dahl old world bluestem [WW-B. Dahl; *Bothriochloa bladhii* (Retz.), S.T. Blake, 1969] is the most recently released variety of a group of grasses from the genus *Bothriochloa*. Information about forage quality and mineral composition for this grass is limited although there is evidence that indicates a high potential of WW-B. Dahl as grazed forage in the Texas High Plains. Non-grazed forage was harvested at monthly intervals or forage was grazed for 0, 38, and 60 d to determine effects of harvesting strategy on yield, botanical and morphological composition, nutritive value, and mineral composition in 2001, 2002, and 2003. Each clipping and grazing treatment was replicated three times in a complete randomized block design with a split-plot arrangement of grazing intervals. Leaves were higher in concentrations of CP, acid insoluble ash, Ca, S, and Cu and were lower in NDF, hemicellulose, and Zn than stems. By July, non-grazed forage was higher in lignin than grazed forage. Concentrations of K were higher in leaves than stem by July.

Concentrations of K and Cu were higher and Fe was lower in non-grazed than grazed forage but few other differences were observed. Within the growing season, percentage CP decreased while NDF increased but seasonal patterns of change appeared to reflect timing of N fertilization and irrigation water applications as well as morphological changes and stage of maturity. Differences in mineral concentration among morphological components were not large enough to reflect differences in morphological fractions due to grazing. WW-B. Dahl is a productive grass, adapted to both hay and grazing but would require supplementation with CP, P, S, Cu, and Zn to meet nutritional needs of most livestock.

Introduction

Old world bluestems (*Bothriochloa spp.*) mainly *B. ischaemum* varieties have been extensively used in northwest Texas under the Conservation Reserve Program (CRP). Approximately 1.62 million ha in this area have been established to grass in this program and it is estimated that about 303,514 ha were seeded to one of the varieties of old world bluestem (Bell and Caudle, 2000). This includes pure stands as well as mixtures in which old world bluestem was a major component.

Although, information regarding biomass yield and nutritive value of old world bluestems exists, this is limited and in the majority of cases, research refers to *B. ischaemum* varieties. Furthermore, information about mineral composition of *Bothriochloa spp*. is practically non-existent. WW-B. Dahl [*Bothriochloa bladhii* (Retz.), S.T. Blake] was introduced to the Texas High Plains in 1960 (Dewald *et al*., 1995) and its use by producers is expanding rapidly. Results from Allen (1999), Philipp (2004), and Niemann (2001; unpublished data, Texas Tech University), Allen *et al.* (2005), indicate a high potential of WW-B. Dahl to be used as grazing forage in the Texas High Plains but little is known regarding defoliation strategies or effects of grazing vs. no grazing on forage quality and morphology.

The objective of this study was to compare the effect of three grazing periods and six clipping intervals on WW-B. Dahl biomass yield, botanical and morphological composition, forage quality, and mineral concentration.

Materials and methods

In May 2001, two experiments were established within the WW-B. Dahl component of an integrated crop-livestock system (see Chapter 2) to investigate effects of defoliation strategies on WW-B. Dahl. Both experiments were conducted during three growing seasons from May 2001 until November 2003.

Experiment 1. Defoliation by grazing

In late May, when steers began continuously grazing spring growth of WW-B. Dahl, three grazing intervals were imposed as 1) a non-grazing (0 d), 2) a short grazing period (38 d) starting in late May and ending in mid-June, and 3) a long grazing period (60 d) starting in May and ending in mid-July, when all grazing activity was terminated and steers were removed from the pasture. Seven Angus cross-breed steers (initial BW = 243 kg; SD = 19) grazed each replication from January to late July each year in sequence with rye and wheat. When steers returned to WW-B. Dahl in May they grazed continuously until the end of treatments 2 and 3. A full description of grazing treatments is given in the previous chapter.

Irrigation and fertilizer applications were made through a sub-surface drip tape irrigation system buried at 1 m. Total amount of water supplied (irrigation plus precipitation; Fig 3.1) averaged 638 mm for the 3 yr of research. Precipitation averaged 359 mm (SE = 108), while water applied through irrigation averaged 279 mm (SE = 10). Fertilization consisted of 72 kg ha^{-1} of N applied in August of each yr and 60 kg ha^{-1} of P applied in August of 2003. Irrigation was used to promote forage growth while steers grazed until mid-July. Following removal of steers, irrigation was reduced in July but was increased again when N was applied in August to promote autumn growth and seed production.

Forage samples were collected in all treatments at three dates each yr: 1) in early May before grazing began, 2) in June when the short grazing period ended, and, 3) in July at the end of the long grazing period. Aboveground biomass samples were taken at 5 cm, from two, 0.30 x 0.40 m quadrants placed randomly within each treatment at each sampling date. Forage samples were placed in brown paper bags and weighed in the field immediately after cutting. Individual samples were frozen until they were hand separated into WW-B. Dahl leaf and stem, weed, and dead material. Separated components were dried at 55 °C in a forced air oven to a constant weight and dry weights were then recorded.

For each sampling date, biomass yield, botanical composition, forage quality and mineral concentration were estimated. Total biomass on a dry basis was obtained by adding dry weights of the four botanical components. Botanical composition on dry basis was calculated directly with the dry weights at 55 °C of each component. After dry weights were obtained, WW-B. Dahl leaf and stem components were ground to pass a 1-mm screen and forage quality parameters including crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), hemicellulose, cellulose, lignin, acid insoluble ash, DMD, total non-structural carbohydrates (TNC) were determined by laboratory procedures. Samples were scanned into a near-infrared (NIR) spectrophotometer (NIRSystems, Inc., Model # 5000, Silver Spring, MD) to obtain a subset of samples that were analyzed by conventional procedures. Absorption characteristics were determined using NIRS 2 version 3.10 software (NIRSystems, Inc., Silver Spring, MD). Crude protein was determined by a LECO FP-2000 Nitrogen-Protein Determinator (LECO Co., St. Joseph, MI 49085). Neutral detergent fiber (NDF), ADF, hemicellulose, cellulose, lignin and acid insoluble ash were determined using the methodology described by Van Soest (1963), Goering and Van Soest (1970), and Van Soest (1991). Dry matter digestibility (DMD) was calculated as DMD(%) = 88.9 – (0.779 * ADF) using the equation proposed by Linn and Martin (1989). Digestible biomass (DB) was calculated as DB = forage mass * DMD. Total non-structural carbohydrate percentage was estimated using the modified procedure described by Mounsif (1986) which is based on comparisons of spectral absorbance of carbohydrates in forages and glucose or dextrose standards. In this case, the modification of the procedure consisted of preparing standards to have dextrose concentrations of 0.1, 0.2, 0.3 and 0.4 mg ml^{-1} and to build a regression model based on the resulting spectra from these standards to which forage samples were compared. Spectral absorbance for standards and forage samples were measured with a spectrophotometer (Bausch & Lomb, Rochester, NY 14625). Concentrations of Al, Ca, K, Mg, Na, P, S, Cu, Fe, Mn, and Zn, were determined using a 3:1 nitric:perchloric acid digestion (Muchovej, *et al*., 1986). Concentrations in solution were measured by atomic emission with a Thermo-Jarred Ash inductively coupled plasma spectrophotometer.

Statistical analyses were as a completely randomized block design with a split-plot arrangement of grazing intervals (Steel and Torrie, 1981). Effects of treatments on response variables were tested using the GLM procedure of SAS (SAS, 1999). Means were separated by Tukey's test (Steel and Torrie, 1981).

Experiment 2. Defoliation by clipping

In late May 2001, a 4.8 x 4.8 m area was excluded from grazing and divided into six small plots of 0.84 x 1.56 m. In each small plot, one of six initial clipping intervals was randomly assigned. Initial clipping intervals were every 30 d from late May through late October of each yr. A final clipping occurred in October in all plots. For all treatments, the same areas were maintained under the same treatment over three growing seasons. In 2001, dormant WW-B Dahl was removed by grazing, prior to setting the cages in place. In 2002 and 2003, dormant WW-B. Dahl was manually removed in January. Fertilization and irrigation practices were similar to those explained in the previous section.

Forage samples consisted of the total aboveground biomass from the corresponding plot taken at 5 cm with a Jari Trail Buster mower (Year-A-Round Corp., Mankato, MN.). Forage samples were placed in brown paper bags and weighed in the field immediately after cutting. Individual samples were frozen until they were hand separated into WW-B. Dahl, weed, and dead material. Separated components were dried at 55 °C in a forced air oven until constant weight was achieved and dry weights were then recorded.

For each initial and final clipping date, total biomass and botanical composition were estimated. Additionally, for each initial clipping date forage quality and mineral concentration were also estimated. Biomass yield and botanical composition on a dry basis were calculated directly with the dry weights at 55 °C of each component. Total seasonal biomass accumulation on dry basis was calculated by adding the initial and final clipping weights of WW.B. Dahl samples from a given plot. After dry weights were obtained, WW-B. Dahl whole plant samples were grounded to pass a 1-mm screen and CP, NDF, ADF, hemicellulose, cellulose, lignin, acid insoluble ash, DMD, TNC, DB were determined as described above.

Statistical analysis of the data was as a completely randomized block design (Steel and Torrie, 1981). Effects of treatments on response variables were tested using the GLM procedure of SAS (SAS, 1999). Means were separated by Tukey's test (Steel and Torrie, 1981).

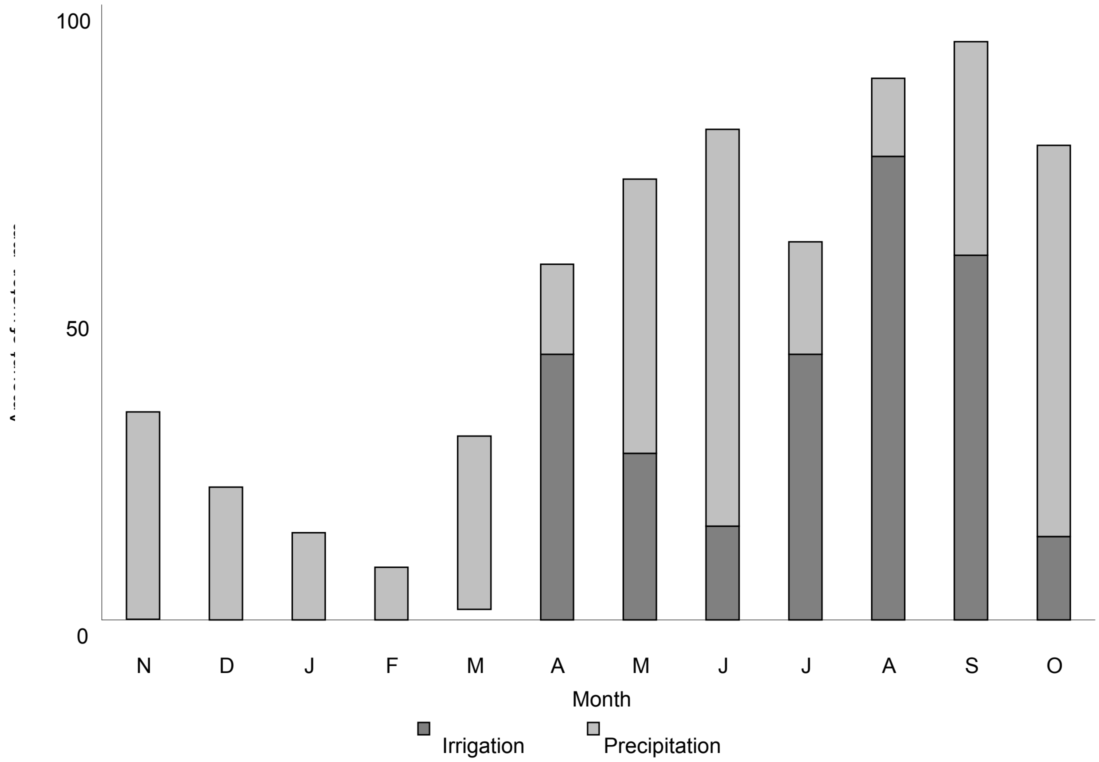

Fig. 3.1. Amount of water supplied through irrigation and precipitation to a WW-B. Dahl perennial pasture grazed and harvested at different intervals averaged across 2001 2002, and 2003 at New Deal, TX.

Results

Experiment 1. Defoliation by grazing

Botanical and morphological composition

Because seasonal distribution of forage growth was of interest, effects of grazing period on botanical and morphological components of WW-B. Dahl are presented by month, but no interaction between morphology and grazing period was present ($P > 0.05$). Results were also averaged across 2001, 2002, and 2003 because there was no interaction ($P > 0.05$) between yr and month (Table 3.1; Fig 3.2-3.3).

Forage mass, leaf, stem, dead material, weeds, and leaf/stem ratio (L/S) did not differ ($P > 0.05$) among grazing treatments in May. By June, forage mass increased in the non-grazed with respect to that in May. Forage mass, leaf, stem, and weeds were higher ($P < 0.05$) in non-grazing than in grazed areas. No difference ($P > 0.05$) was observed in amount of dead material or in L/S among the three treatments. By July, the pattern observed in June prevailed except that no further increase in biomass of non-grazed areas was observed. Non-grazed total biomass and leaf and stem weights were greater ($P < 0.05$) than when grazing occurred but no difference ($P > 0.05$) was observed between short and long grazing periods. No differences ($P > 0.05$) were observed in the amount of dead material and L/S among non-grazed and grazed treatments.

More weed ($P < 0.05$) was present in non-grazed areas than in either of the grazed areas in June. The primary species present were silver leaf nightshade

(*Solanum elaeagnifolium* Cav.) and Texas bindweed (*Convolvulus equitans* Benth.). In July, there was no difference (*P* > 0.05) in amount of weeds present among grazed and non-grazed areas due to the high variation among replications.

<u>Nutritive value</u>

In the case of grazed forages, it is important to know not only when but also, where the qualitative changes occur, therefore, although there was no interaction (*P* > 0.05) between month and grazing period and month and morphology, effects of grazing period and morphological component are presented by month.

At the begging of May, WW-B. Dahl was starting its spring growth and biomass production was almost entirely of leaves, thus, forage quality analyses were made only on leaf tissue (Table 3.2). Effects of grazing on forage quality were averaged across years because no interactions were present (*P* > 0.05). At this point, no grazing activity had occurred since the end of grazing dormant forage in March, thus, this date is consider the starting point of the growing season. At this date, CP, ADF, Cellulose, lignin, ash, hemicellulose, TNC, DMD, and digestible biomass of leaves were not different (*P* > 0.05) among grazing periods; however, NDF was higher (*P* < 0.05) in the short-term grazed areas, and lower (*P* < 0.05) in the non-grazed areas, but actual differences were small.

In June, there was enough stem (defined as stem plus leaf sheath) material to conduct analysis. Effects of grazing and morphology on forage quality were averaged across years because no interactions were present ($P > 0.05$).

Additionally, effects of morphology on CP, NDF, ADF, cellulose, lignin, ash, hemicellulose, and TNC were averaged across grazing period (month) because there were no interactions ($P > 0.05$) between grazing period and morphological component; however, at this date, there was an interaction ($P < 0.05$) between grazing period and morphological component affecting digestible biomass. Although they did not differ ($P > 0.05$) leaf and stem digestibility were numerically higher in the non-grazed than grazed treatments. Leaf digestibility was numerically higher in the short grazing period than in the long grazing period, while for stem the opposite occurred (Table 3.3). None of the other forage quality components were different ($P > 0.05$) among grazing treatments. Crude protein, lignin, and ash were higher ($P < 0.05$) in leaves than stems while NDF, cellulose, and hemicellulose were higher ($P < 0.05$) in stems than leaves (Table 3.4). Percentage ADF, TNC, and DMD were similar ($P > 0.05$) between leaf and stem.

In July, effects of grazing and morphology on forage quality were averaged across years because no interactions were present ($P > 0.05$). Additionally, effects of morphology on CP, NDF, ADF, cellulose, lignin, ash, hemicellulose, and digestible biomass were averaged across grazing period because there was no interaction ($P > 0.05$) between grazing period and morphological component; however, at this date, there was an interaction ($P < 0.05$) between grazing period and morphological component affecting TNC and data are presented separately (Table 3.5). Lignin was higher ($P < 0.05$) in the non-grazed than grazed forage, but the rest of the forage quality components were similar ($P > 0.05$) among grazing periods.

Crude protein and ash were higher ($P < 0.05$) in leaves than stems while NDF, cellulose, and hemicellulose were higher ($P < 0.05$) in stems; and ADF, lignin, DMD, and DB were similar ($P > 0.05$) between leaf and stem (Table 3.6).

Mineral concentration

As in the case of forage quality, effects of grazing period and morphological component on mineral concentrations of Al, Ca, K, Mg, Na, P, S, Cu, Fe, Mn, and Zn for WW-B. Dahl are also presented by month although there was no interaction ($P > 0.05$) between month and grazing period and month and morphology, In May, June, and July, effects of grazing on mineral concentrations were averaged across years because no interactions were present ($P > 0.05$). Additionally, in June and July, effects of morphology on mineral concentration were averaged across grazing period because there was no interaction ($P > 0.05$) between grazing period and morphological component.

Copper contamination occurred at the time of grinding due to Cu contained in the grinding ring of the grinder and affected all forage samples, thus, although concentrations of this element are higher than they should have been, the contamination appeared uniform and differences appear valid.

Table 3.1. Effect of grazing period on botanical and morphological composition of a WW-B. Dahl old world bluestem pasture at New Deal, TX. averaged across 2001, 2002, and 2003.

Item	Grazing period			SE[†]
	Non-grazing	Short term	Long term	
May				
Total Biomass, kg ha^{-1}	3,845	2,962	3,967	639
Leaf, kg ha^{-1}	1,746	1,224	1,588	289
Stem, kg ha^{-1}	2	0	0	1
Dead, kg ha^{-1}	1,941	1,724	2,371	596
Weed, kg ha^{-1}	156	13	8	55
L/S[‡]	28	0	0	16
June				
Total Biomass, kg ha^{-1}	9,465[a]	3,533[b]	3,285[b]	652
Leaf, kg ha^{-1}	6,617[a]	2,143[b]	1,854[b]	280
Stem, kg ha^{-1}	1,664	166[b]	284[b]	211
Dead, kg ha^{-1}	944	1,222	1,147	182
Weed, kg ha^{-1}	241[a]	1[b]	0[b]	39
L/S[‡]	6	8	8	4
July				
Total Biomass, kg ha^{-1}	8,901[a]	4,163[b]	3,394[b]	966
Leaf, kg ha^{-1}	4,805[a]	2,434[b]	1,484[b]	393
Stem, kg ha^{-1}	1,596[a]	406[b]	385[b]	173
Dead, kg ha^{-1}	1,894	1,319	1,287	227
Weed, kg ha^{-1}	663	4	2	242
L/S[‡]	3	6	6	2

[a,b] Means with different letter within a row were different (*P* < 0.05).
[†] SE = standard error of the mean.
[‡] Leaf:Stem ratio calculated as leaf mass divided by stem mass.

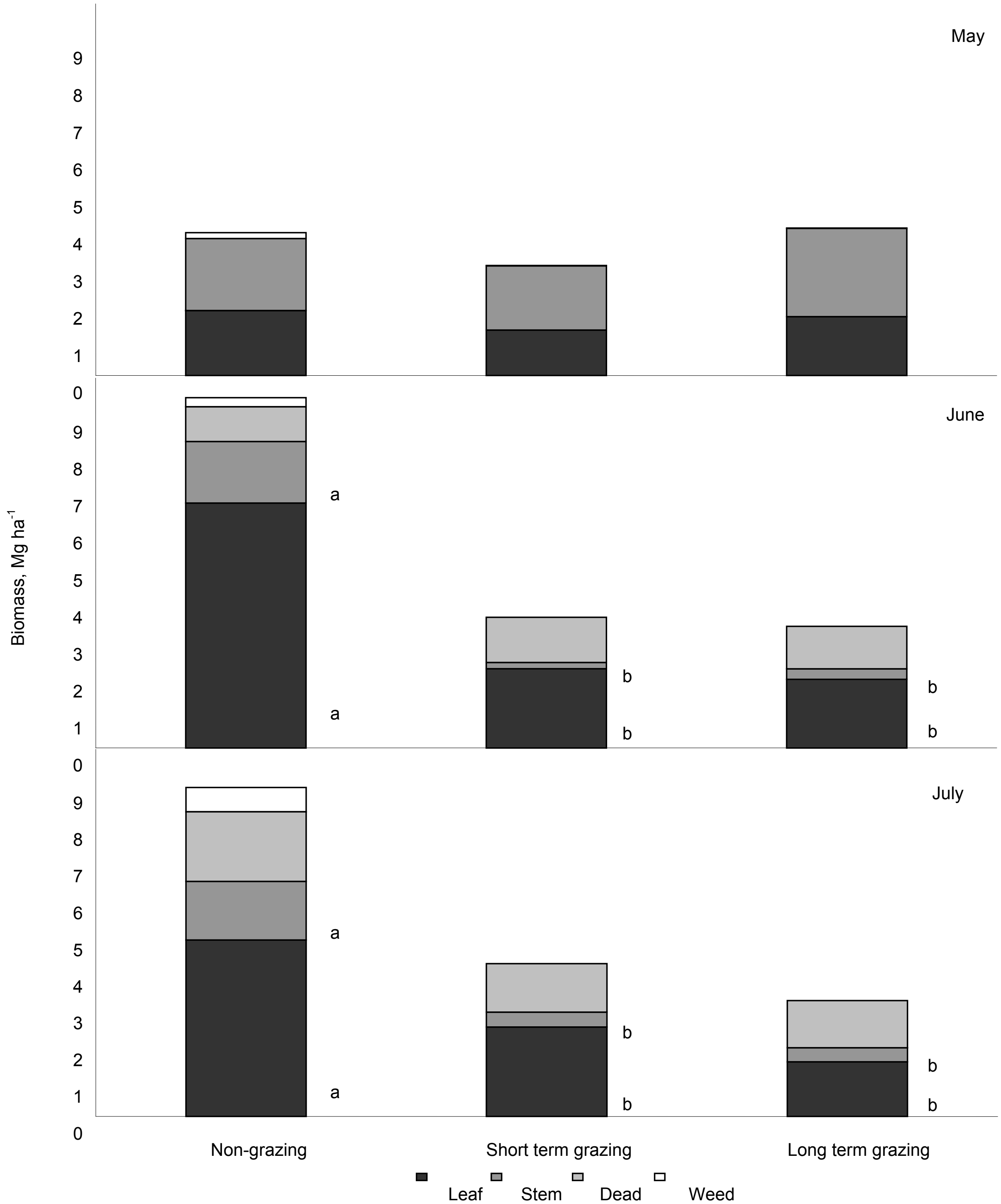

Fig. 3.2. Botanical composition a WW-B. Dahl perennial pasture grazed at different intervals in 2001 2002, and 2003 at New Deal, TX.

[a,b] Means with the same letter within a yr were not different ($P > 0.05$).[†] SE = standard error of the mean.

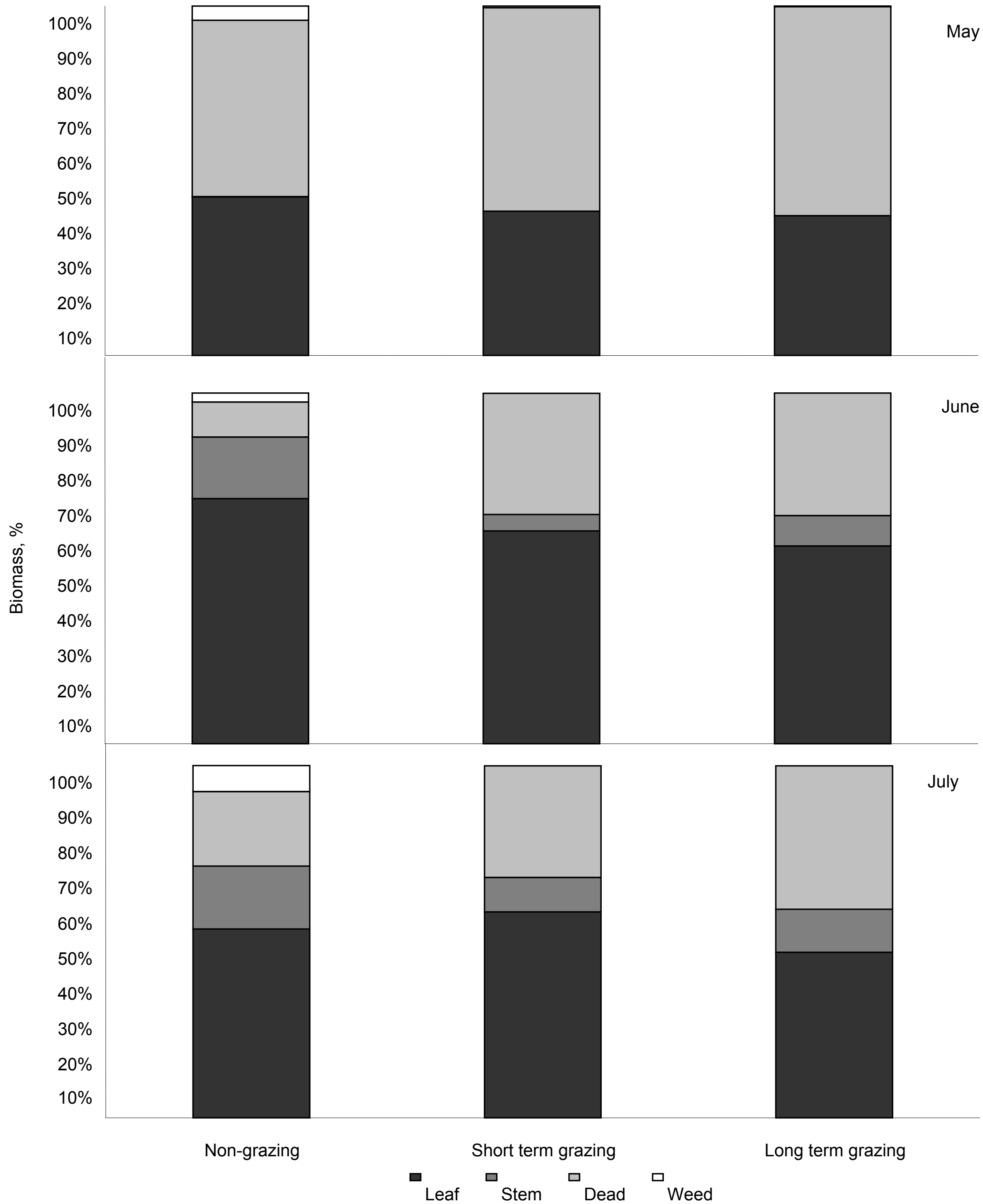

Fig. 3.3. Percentages of botanical and morphological components of a WW-B. Dahl perennial pasture grazed at different intervals in 2001 2002, and 2003 at New Deal, TX.

Table 3.2. Effect of grazing period on forage quantity and quality of leaves of WW-B. Dahl in May before spring grazing at New Deal, TX averaged across 2001, 2002, and 2003.

Item	Grazing period			
	Non-grazing	Short term	Long term	SE[†]
	--------------------------g $100g^{-1}$	---------------------------		
CP	14.6	14.8	14.1	0.5
NDF	69.4b	70.5a	70.2ab	0.2
ADF	42.8	45.3	44.7	1.0
Cellulose	28.4	31.6	30.7	1.0
Lignin	5.7	5.5	5.5	0.4
Ash	9.0	9.4	9.4	0.6
Hemicellulose	26.6	25.2	25.5	0.9
TNC	5.8	5.9	6.3	0.7
DMD[§]	56.4	54.6	55.1	0.8
Digestible leaf[‡]	973	654	851	159

[a,b] Means with different letter within a row were different ($P < 0.05$).
[†] SE = standard error of the mean.
[‡] Calculated as forage mass X DMD.
[§] Calculated as DMD(%) = 88.9 – (0.779 * ADF).

Table 3.3. Effect of grazing period on forage quantity and quality of WW-B. Dahl in June at the end of the short-term grazing period at New Deal, TX averaged across 2001, 2002, and 2003 and across morphologic component.

	Grazing period			
Item	Non-grazing	Short term	Long term	SE[†]
	------------------------------g 100g-1-----------------------------			
CP	7.6	8.9	8.8	0.9
NDF	75.1	74.9	73.7	1.7
ADF	48.0	47.2	45.4	1.2
Cellulose	36.4	34.3	33.3	1.3
Lignin	5.8	5.7	5.5	0.2
Ash	7.4	8.8	8.0	1.0
Hemicellulose	27.1	26.1	28.4	2.0
TNC	7.1	8.2	8.9	1.1
DMD[§]	52.5	53.1	54.6	0.9
DB[‡]				
Leaf	3,142[a]	1,126[a]	989[a]	1,752
Stem	787[a]	142[a]	313[a]	414
SE[†]	326	407	392	

[†] SE = standard error of the mean.
[a,b] Means with different letter within a row were different ($P < 0.05$).
[‡] Calculated as DB = forage mass X DMD
[§] Calculated as DMD(%) = 88.9 – (0.779 * ADF).

Table 3.4. Forage quality of leaves and stems of WW-B. Dahl in June at the end of the short-term grazing period at New Deal, TX averaged across 2001, 2002, and 2003 and across grazing treatment.

Item	Plant component		
	Leaf	Stem	SE[†]
	-----------------g 100g-1----------------		
CP	9.7	5.3*	0.4
NDF	71.8	79.8*	0.7
ADF	47.0	47.3	1.1
Cellulose	33.3	37.8*	0.9
Lignin	5.8	5.4*	0.2
Ash	9.5	5.5*	0.5
Hemicellulose	24.8	31.6*	1.2
TNC	7.8	9.2	0.9
DMD[‡]	53.3	53.1	0.9

[*] Indicates differences between means ($P < 0.05$).
[†] SE = standard error of the mean.
[‡] Calculated as DMD(%) = 88.9 – (0.779 * ADF).

Table 3.5. Effect of grazing period on forage quality of WW-B. Dahl in July at the end of the long-term grazing period at New Deal, TX averaged across 2001, 2002, and 2003 and across morphologic component.

Item	Grazing period			
	Non-grazing	Short term	Long term	SE[†]
	---------------------------g 100g-1--------------------------			
CP	7.3	8.1	7.6	0.9
NDF	74.0	74.5	75.1	1.2
ADF	50.4	48.3	47.4	0.7
Cellulose	38.3	35.1	34.8	1.1
Lignin	6.6a	6.1b	6.0b	0.1
Ash	7.3	8.7	7.9	0.7
Hemicellulose	23.6	24.6	26.8	1.1
TNC				
Leaf	10.1	9.2	7.9	
Stem	9.8	12.4	9.2	
SE[†]				
DMD[§]	50.6	52.3	53.0	0.6

[a,b] Means with different letter within a row were different (*P* < 0.05).
[†] SE = standard error of the mean.
[‡] Calculated as forage mass X DMD
[§] Calculated as DMD(%) = 88.9 – (0.779 * ADF).

Table 3.6. Forage quality of leaves and stems of WW-B. Dahl in July at the end of the long-term grazing period at New Deal, TX averaged across 2001, 2002, and 2003 and across grazing treatments.

Item	Plant component		
	Leaf	Stem	SE†
	----------------g $100g^{-1}$---------------		
CP	9.5	4.3***	0.3
NDF	71.7	79.3***	0.5
ADF	48.2	49.8	0.7
Cellulose	34.6	39.6*	0.9
Lignin	6.2	6.2	0.2
Ash	9.2	5.1**	0.4
Hemicellulose	23.5	28.7**	0.8
DMD‡	52.3	51.1	0.6
DB§	1,578	536	231

*,**,*** Indicates differences between means (*P* < 0.05; *P* < 0.01; and *P* < 0.001, respectively).
† SE = standard error of the mean.
‡ Calculated as DMD(%) = 88.9 – [0.779 * ADF(%)].
§ Calculated as DB = forage mass X DMD

In May, no grazing activity had occurred since the end of grazing dormant forage in March (Table 3.7). At this point WW-B. Dahl was starting its spring growth, therefore, mineral analyses were conducted only in leaf tissue. At this date mineral concentrations did not differ ($P > 0.05$) among grazing periods.

In June, Cu concentration in WW-B. Dahl was lower ($P < 0.05$) in non-grazed than in grazed areas (Table 3.8). Zinc was higher ($P < 0.05$) in non-grazed than in grazed forage. Concentrations of other minerals did not differ ($P > 0.05$) among grazing periods. At this date, Al, Ca, Na, S, Cu, and Fe were higher ($P < 0.05$) in leaves than stems while Zn and Mn were higher ($P < 0.05$) in stems than leaves; K, Mg, and P were similar ($P > 0.05$) between leaf and stem (Table 3.9).

In July, Fe was lower ($P < 0.05$) in the non-grazed than in grazed WW-B. Dahl while K, S, and Zn concentrations were higher ($P < 0.05$) in the non-grazed than in the grazed forage (Table 3.10). The rest of the minerals were similar ($P > 0.05$) among grazing periods. At this date, Ca, K, Mg, P, S, and Cu and were higher ($P < 0.05$) in leaves than stems while Zn and Mn were higher ($P < 0.05$) in stems than leaves; Al, Na, and Fe were similar ($P > 0.05$) between leaf and stem (Table 3.11).

Table 3.7. Effect of grazing period on mineral concentration of leaves of WW-B. Dahl in May before spring grazing at New Deal, TX averaged across 2001, 2002, and 2003.

	Grazing period			
	Non-grazing	Short term	Long term	SE[†]
Macro-mineral, g kg^{-1}				
Al	0.9	0.7	0.8	0.07
Ca	11	10	11	0.6
K	15	16	16	0.7
Mg	2	2	2	0.2
P	2	2	2	0.08
S	1.5	1.4	1.4	0.05
Micro-mineral, mg kg^{-1}				
Cu	29	26	27	0.9
Fe	335	253	308	36
Mn	85	87	88	8
Na	100	100	100	10
Zn	25	21	20	1

[a,b] Means with different letter within a row were different ($P < 0.05$).
[†] SE = standard error of the mean.

Table 3.8. Effect of grazing period on mineral concentration of WW-B. Dahl in June at the end of the short-term grazing period at New Deal, TX averaged across 2001, 2002, and 2003 and across morphologic component.

	Grazing period			
	Non-grazing	Short term	Long term	SE[†]
Macro-mineral, g kg^{-1}				
Al	0.7	0. 9	1	0.1
Ca	8	9	9	0.4
K	17	15	16	0.9
Mg	2	2	2	0.06
P	1	1	1	0.07
S	0. 9	0. 8	0.8	0.05
Micro-mineral, mg kg^{-1}				
Cu	15[b]	20[a]	18[b]	2
Fe	239	378	429	76
Mn	62	58	60	5
Na	90	100	90	9
Zn	24[a]	19[b]	17[b]	2

[a,b] Means with different letter within a row were different ($P < 0.05$).
[†] SE = standard error of the mean.

Table 3.9. Mineral concentration of leaves and stems of WW-B. Dahl in June at the end of the short-term grazing period at New Deal, TX averaged across 2001, 2002, and 2003 across grazing treatments.

	Plant component		
	Leaf	Stem	SE[†]
Macro-mineral, g kg^{-1}			
Al	0.9	0.7**	0.1
Ca	9	7***	0.2
K	16	15	0.8
Mg	2	2	0.06
P	1	1	0.08
S	0.9	0.7**	0.03
Micro-mineral, mg kg^{-1}			
Cu	21	10**	1.0
Fe	397	234*	67
Mn	53	73***	4
Na	100	80**	6
Zn	18	25**	1

*,**,*** Indicates differences between means (*P* < 0.05; *P* < 0.01; and *P* < 0.001, respectively).
[†] SE = standard error of the mean.

Table 3.10. Effect of grazing period on mineral concentration of WW-B. Dahl in July at the end of the long-term grazing period at New Deal, TX averaged across 2001, 2002, and 2003 and across morphologic component.

	Grazing period			
	Non-grazing	Short term	Long term	SE[†]
Macro-mineral, g kg^{-1}				
Al	0.6	0.9	1	0.1
Ca	9	10	9	4
K	19[a]	15[b]	16[b]	0.8
Mg	2	2	2	0.1
P	1	1	1	0.1
S	1[a]	0.9[b]	0.9[b]	0.04
Micro-mineral, mg kg^{-1}				
Cu	15	16	16	1
Fe	192[b]	371[a]	502[a]	89
Mn	56	56	59	4
Na	100	100	100	10
Zn	23[a]	19[b]	20[b]	2

[†] SE = standard error of the mean.
[a,b] Means with different letter within a row were different ($P < 0.05$).

Table 3.11. Mineral concentration of leaves and stems of WW-B. Dahl in July at the end of the long-term grazing period at New Deal, TX averaged across 2001, 2002, and 2003 and across grazing treatments.

	Plant component		
	Leaf	Stem	SE†
Macro-mineral, g kg^{-1}			
Al	0.9	0.9	0.07
Ca	10	7***	0.2
K	17	14**	0.6
Mg	2	2**	0.06
P	1	1*	0.06
S	0.9	0.7***	0.02
Micro-mineral, mg kg^{-1}			
Cu	17	10**	0.8
Fe	341	416	61
Mn	52	72***	2
Na	100	100	10
Zn	20	25**	1

† SE = standard error of the mean.
*,**,*** Indicates differences between means (*P* < 0.05; *P* < 0.01; and *P* < 0.001, respectively).

Experiment 2. Defoliation by clipping

Forage mass and total seasonal yield

Growth and regrowth after initial harvest of WW-B. Dahl were averaged across the three growing seasons because there was no interaction ($P > 0.05$) between year and month.

Seasonal distribution of forage mass production and growth pattern was influenced by irrigation and fertilization strategy and flowering habit of WW-B. Dahl. Forage mass was higher in previously uncut forage in October than in other months at first harvest, demonstrating that WW-B. Dahl continued to grow and accumulate biomass over the growing season (Table 3.12).

The time of most rapid growth corresponded with application of N fertilizer and an increase in irrigation that occurred in early August. When growth was examined by month as a change from the previous month, the pattern resembled the typical growth curve for warm-season perennial grasses but exhibited a depression in growth in mid-summer when irrigation was reduced following termination of grazing by steers in the surrounding pasture (Fig 3.4). Total seasonal yield was higher when plots were harvested first in May and September and then again in October than when the first harvest occurred in June. It was evident that total seasonal yield was affected by when the first harvest was taken.

Table 3.12. Effect of clipping date on forage quality of WW-B. Dahl at New Deal, TX averaged across 2001, 2002, and 2003.

Component	Harvest date						
	May	June	July	Aug.	Sept.	Oct.	SE[†]
	Mg ha^{-1}						
Initial harvest	2.6[c]	2.1[c]	4.1b[c]	5.5[b]	9.3[a]	9.7[a]	0.7
Final harvest[‡]	6.8[a]	2.9[b]	2.9[b]	1.9b[c]	1.0[cd]	0.0[d]	0.5
Total seasonal yield	9.4[a]	5.0[b]	7.0[ab]	7.4[ab]	10.3[a]	9.7[ab]	1.0

[a,b] Means with different letter within a row were different ($P < 0.05$).
[†] SE = standard error of the mean.
[‡] All plots were harvested for the second time in October.

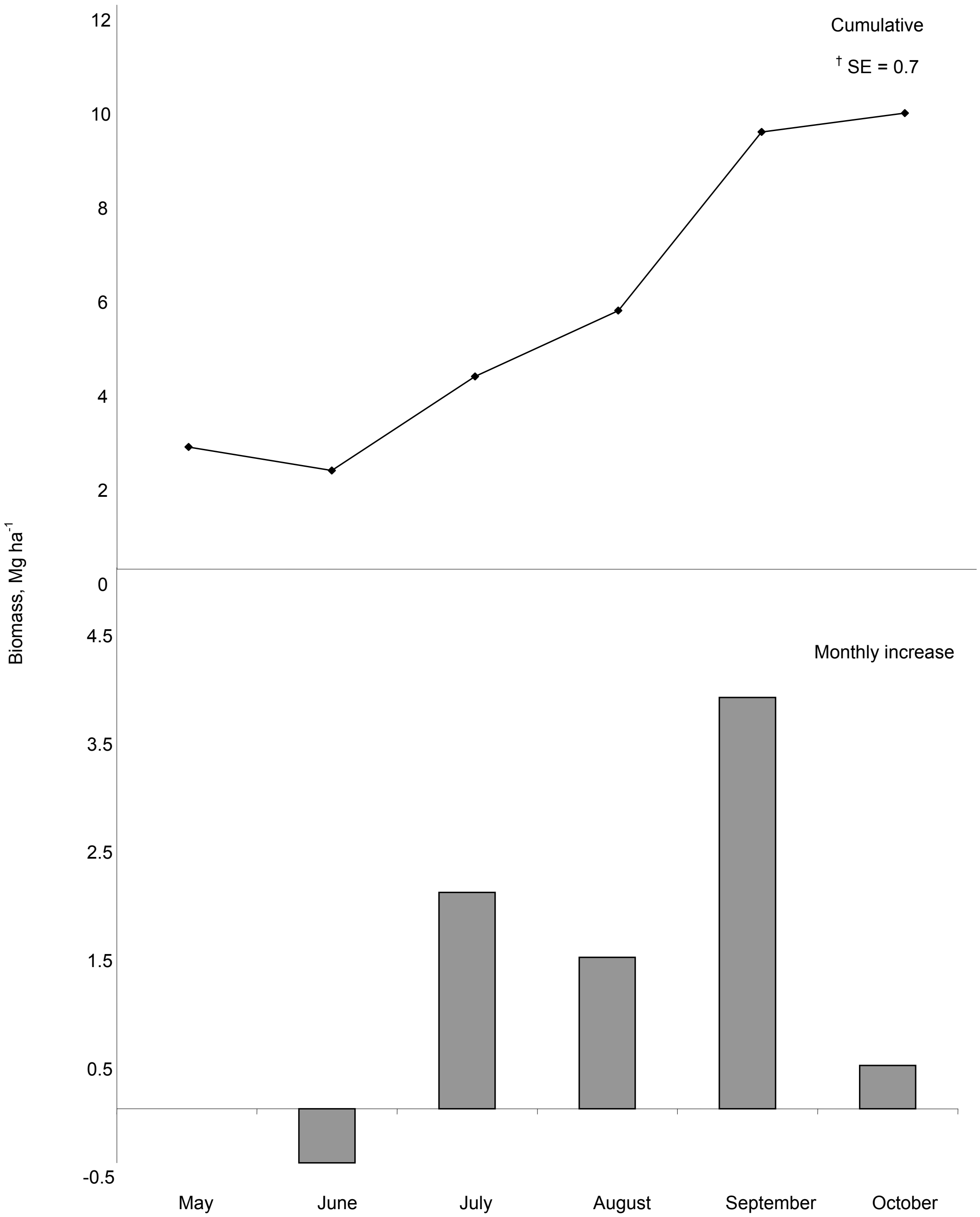

Fig. 3.4. Cumulative and monthly growth curves of WW-B. Dahl harvested every 30 d averaged across 2001, 2002 and 2003, at New Deal, TX.

Forage quality components were consistent among years [no interaction ($P > 0.05$) between year and month]. In forages considered for purposes including grazing, making hay, or producing seed, it is important to know qualitative characteristics throughout the growing season and when changes occur in order to plan for efficient use. Thus, results for this experiment are presented by date of sampling (Table 3.13). Crude protein content declined ($P < 0.05$) from May to October, with the highest ($P < 0.05$) percentage in May. Neutral detergent fiber concentrations were constant ($P > 0.05$) from May to August, but increased ($P < 0.05$) during the rapid growth phase by September and October. Acid detergent fiber percentages varied throughout the season. They were similar ($P > 0.05$) in May, June, July and October. September ADF percentage was lower ($P < 0.05$) than October's but similar ($P > 0.05$) to that found from May to August. Cellulose concentration was similar ($P > 0.05$) from May throughout September, although July and September concentrations did not differ ($P > 0.05$) from those in October. Acid insoluble ash percentage in May, June and July was higher ($P < 0.05$) than in August, September, and October. No differences ($P > 0.05$) were observed between months with higher or lower ash percentage. Hemicellulose concentrations were similar ($P > 0.05$) throughout to August. It was at its highest ($P < 0.05$) in September and October, although October's hemicellulose concentration did not differ ($P > 0.05$) from that of August. Lignin was similar ($P > 0.05$) from May to June and also in October. Although August and September levels did not differ ($P > 0.05$) from those in October, and particularly in August, lignin levels were also similar to those in June and July. Percentage TNC was not different ($P > 0.05$) throughout the season. DMD percentage was similar ($P > 0.05$) in May, August and September. September percentages were similar ($P > 0.05$) to percentages in June and July. October concentration was similar ($P > 0.05$) to May, June, and July.

Mineral concentration

As in the case of forage quality components, concentrations of Al, Ca, K, Mg, Na, P, S, Cu, Fe, Mn, and Zn are presented by month and were averaged across 2001, 2002, and 2003 because there was no interaction ($P > 0.05$) between yr and month (Table 3.14). Concentrations of most minerals were at their highest in May and June and then declined over the growing season. Exceptions were Mg and Na which remained relatively constant throughout the growing season.

Concentrations of Al were highest ($P < 0.05$) in May and June with intermediate ($P < 0.05$) levels in July until they reached the lowest ($P < 0.05$) concentration by September and October. August concentrations did not differ from concentrations found in July, September and October.

Calcium concentration was similar from May to August and declined ($P < 0.05$) by September and October. Potassium concentration did not vary from May to September, although, May and September concentrations were similar ($P > 0.05$) to those in October. June, July and August concentrations were higher ($P < 0.05$) than those found in October. Magnesium concentration was similar from May to August and in October; however, September concentration was only lower ($P < 0.05$) than May concentration. Sodium concentrations were constant ($P > 0.05$) throughout the growing season. Sulfur concentration was highest ($P < 0.05$) in May, intermediate ($P < 0.05$) in June and August and lowest ($P < 0.05$) in July, September and October. Concentrations of Cu were at their highest ($P < 0.05$) in May and June with intermediate ($P < 0.05$) levels in July and August until they reached the lowest ($P < 0.05$) concentration by September and October. Iron was at its highest ($P < 0.05$) in May and June with no change ($P > 0.05$) in late season. Concentration of Mn was similar ($P > 0.05$) in May, June and from August to October. Although July percentage was lower ($P < 0.05$) than concentration in May, June, September, and October, it did not differ from August values. Zinc was at its highest ($P < 0.05$) in May with no further differences for the rest of the season.

Table 3.13. Effect of clipping date on forage quality of WW-B. Dahl at New Deal, TX averaged across 2001, 2002, and 2003.

Item	Clipping date						
	May	June	July	Aug.	Sept.	Oct.	SE[†]
				g $100g^{-1}$			
CP	9.4[a]	7.8[b]	5.8[cd]	7.1[cb]	5.0[de]	4.1[e]	0.5
NDF	72.0[4b]	72.1[b]	72.9[b]	71.7[b]	75.8[a]	77.7[a]	0.9
ADF	49.5[abc]	50.1[ab]	50.3[ab]	46.8[c]	47.9[bc]	51.0[a]	0.9
Cellulose	35.5[b]	35.9[b]	37.1[ab]	35.3[b]	37.3[ab]	39.6[a]	0.9
Ash	10.1[ab]	10.5[a]	9.1[b]	7.7[c]	6.2[d]	6.9[cd]	0.4
Hemicellulose	23.2[c]	21.9[c]	22.5[c]	24.9[bc]	27.9[a]	26.7[ab]	0.9
Lignin	6.3[a]	6.1[ab]	6.1[ab]	5.8[bc]	5.5[c]	5.9[abc]	0.1
TNC	9.4	9.3	10.4	10.1	10.0	8.9	0.5
DMD[‡]	51.2[abc]	50.9[bc]	50.7[bc]	53.4[a]	52.6[ab]	50.2[c]	0.7

[a,b,c,d,e] Means with different letter within a row were different ($P < 0.05$).
[†] SE = standard error of the mean.
[‡] Calculated as DMD(%) = 88.9 – (0.779 * ADF).

Table 3.14. Effect of clipping date on mineral concentration of WW-B. Dahl at New Deal, TX averaged across 2001, 2002, and 2003.

	Clipping date						
	May	June	July	Aug.	Sept.	Oct.	SE[†]
Macro-mineral				g kg^{-1}			
Al	1[a]	1[a]	0.8[b]	0.8[bc]	0.5[c]	0.5[c]	0.09
Ca	11[a]	10[a]	10[a]	10[a]	8[b]	9[b]	0.3
K	14[ab]	16[a]	15[a]	15[a]	14[ab]	13[b]	0.7
Mg	2[a]	2[ab]	2[ab]	2[ab]	2[b]	2[ab]	0.1
P	2[a]	1[ab]	1[cd]	1[bc]	0.9[de]	0.8[e]	0.07
S	1[a]	0.9[b]	0.8[c]	1[b]	0.7[c]	007[c]	0.05
Micro-mineral				mg kg^{-1}			
Cu	16[a]	14[a]	13[b]	12[b]	10[c]	9[c]	0.5
Fe	644[a]	800[a]	303[b]	259[b]	182[b]	163[b]	104
Mn	97[a]	84[a]	65[b]	79[ab]	83[a]	91[a]	5
Na	100	100	100	100	100	100	10
Zn	30[a]	24[b]	21[b]	23[b]	21[b]	22[b]	1

[†] SE = standard error of the mean.
[a,b,c,d,e] Means with different letter within a row were different ($P < 0.05$).

Discussion

Forage mass, total seasonal yield, and botanical and morphological composition

Seasonal biomass accumulation measured in this research reflected management strategies used in the grazing system. Irrigation water was allocated through the growing season in order to supplement precipitation as needed to ensure forage for grazing steers. When steers were removed from pastures in July, irrigation water was decreased to a level just sufficient to prevent dormancy in plants. Irrigation was increased by August and September and fertilizer was applied in August to promote seed production and to stockpile WW-B. Dahl for winter grazing by steers.

Forage mass present in the pastures prior the start of grazing, that is, in May of each yr, averaged 3.6 Mg ha^{-1} across 2001-2003 and grazing treatments. Of the forage mass at this time, 1.52 Mg ha^{-1} corresponded to WW-B. Dahl leaves, 2.01 Mg ha^{-1} to dead material, probably dormant grass from the prior season, and less than 0.1 Mg ha^{-1} to WW-B. Dahl stems and weeds respectively. The absence of differences due to grazing treatments at this month is explained by the fact that May was the starting point of the growing season and no grazing treatment was yet imposed on the pastures.

Our data are within the range of biomass reported by Sanderson *et al*. (1999). They observed WW-B. Dahl forage mass in two central Texas locations for May 1994 of 5.0 and 2.0 Mg ha^{-1} under dryland conditions. Phillip (2004), at New Deal, TX, in an experiment carried out on the same years as the current experiment showed forage mass yields in May to be 2.0 Mg ha^{-1} for medium irrigation level (685 mm) which are lower than the forage mass found in this research using about the same amount of water (638 mm).

In June forage mass in the non-grazed areas was 2.7 times as high as in the grazed areas, (9.5 vs. 3.4 Mg ha^{-1}, respectively). Leaves of WW-B. Dahl comprised the majority of the forage produced in all three grazing treatments at this point, although in the non-grazing areas WW-B. Dahl stems and weeds had a high contribution to the total forage mass compared with their contribution in the grazed areas. Dead material was still present at this time in the pasture; however, it was similar in all grazing treatments. Sanderson *et al*. (1999) reported forage masses of 6.0 and 4.0 Mg ha^{-1} for the same grass in June of 1994 and 1995 respectively, and Philipp (2004) reported June biomass yields of 6.0 Mg ha^{-1} with irrigation to replace 66% ET. Both experiments reported lower forage mass than found in this research. At this point results from the mentioned authors can only be compared to results from the non-grazed areas, because neither of their experiments included grazing activity. Discrepancies with Sanderson's *et al*. results also can be related to the fact that their experiment was carried out under dryland conditions and different soil type which reinforces the idea that WW-B. Dahl can adapt to a wide range of natural conditions, although not necessarily at the same performance level. In the case of Philipp's research, discrepancies may be attributed to differences in irrigation strategies. He used a surface irrigation system as opposed to the more efficient subsurface system utilized in this research.

In July, forage mass of the non-grazed areas was 2.4 times higher than in grazed areas (8.9 vs. 3.8 Mg ha^{-1}, respectively). At this time, the same pattern of botanical and morphological composition as in June was observed. Philipp (2004) reported a forage mass of 12.0 Mg ha^{-1} for this month, with irrigation to replace 66% ET, which is higher than our findings. Phillip in his research, applied N fertilizer (> 100 kg ha^{-1}) at rates that showed not to have limited plant growth while N in the current experiment was applied only once per yr in August at 60 kg ha^{-1}. Furthermore, Phillip (2004) showed that about 77% of total potential growth occurs by July, thus, applying N only in August in the current research likely limited growth in the first part of the growing season.

Results from the non-grazed areas can also be compared with results obtained from the clipping experiment in this same research. Forage mass in May, June, and July was lower than obtained in non-grazed areas for the same months. When compared with results from Sanderson *et al*. (1999), May forage mass was similar to that reported for at least one of the locations in central Texas; results are also similar to those reported by Philipp (2004). June forage mass from clipping was lower than that reported by Sanderson *et al*. (1999) and forage mass from clipping from June and July was lower than that reported by Philipp (2004).

It is important to keep in mind when comparing results from the non-grazed areas and from the clipping experiment that the clipping areas were excluded from grazing after 3 yr, while no grazing activity had occurred in the non-grazed areas since the establishment of the pastures in 1997. Thus, grazing activity may have modified growth dynamics of plants but there was little difference between the lengths of the two grazing periods. Furthermore, results in our research showed that grazing activity maintained forage mass at a constant level at any given time (no differences between short and long grazing periods in June and July and among months).

Forage mass at the first harvest in the clipping experiment increased every month as expected up to 9.3 and 9.7 Mg ha^{-1} in September and October respectively. These results agree with the findings of Sanderson *et al*. (1999) of 9.6 Mg ha^{-1} in central Texas for October 1994, although are higher than the 7.6 Mg ha^{-1} reported in October of 1995. In the case of this research, time of defoliation affected the pattern of forage mass production and the total seasonal yield obtained in October (forage mass produced in each month plus the regrowth until October). The peak biomass production of the initial growth was when the first harvest occurred in September and October, dates at which biomass production almost doubled with respect to that occurred on July and August; and it was about 4 times greater than that of May and June. On the other hand, regrowth at the October harvest (2^{nd} harvest) followed an expected pattern, with the highest biomass accumulation after the May harvest and the lowest after the August and September harvests. Philipp (2004) reported that about 77% of the total seasonal growth of WW-B. Dahl occurs by July but in that research water and N fertilizer were applied to be non-limiting for plant growth. In the current experiment, timing of irrigation and fertilization likely influenced this pattern of initial growth in that some irrigation and all fertilization occurred at the end of August, thus, promoting grass growth at the end of the season. Although, these results differ in terms of when warm-season grasses normally reach peak forage mass growth, they are also in agreement with others who found that WW-B. Dahl "is a good forage producer on dryland and an outstanding forage producer under irrigation (Berg *et al*., 2004)." Philipp (2004) suggested that WW-B. Dahl accumulates more biomass between September and October than other *Bothriochloa* species. However, it is important to note that, when researchers report biomass yields, often they do not mention when it was obtained, or they just analyze growth occurring during the summer, which for the case of WW-B. Dahl could not be the most adequate methodology. WW-B. Dahl differed from the other Bothriochloa species in that it flowers late in the season, thus, forage mass in September and October reflected stem elongation as well as leaves.

Accumulation of forage from May to October produced similar seasonal yields when the first harvest was in May and October and slightly lower to those when the first harvest was in September. For the treatments when the first harvest occurred in June, July and August, total seasonal yields were lower but only the June harvest differed significantly from May. The case of July is particularly interesting because in that month usually a hay cut may occur. Philipp (2004) calculated seasonal yields for his research as the forage mass obtained in July plus the forage mass accumulated through October. In his results the total seasonal yield of B. Dahl was about 10 mg ha^{-1} under medium irrigation level, which is higher than the total seasonal yield obtained in this research under the same harvesting strategy but likely reflects timing of fertilizer and water application.

Grazing maintained a forage canopy that was higher in percentage leaf than when managed as hay. In this research, the grazing season was conducted during the vegetative growth phase of the grass and continuous defoliation promoted leaf production. However, when only grazed areas were compared, the length of grazing activity was not enough to cause differences in morphological composition. The lower proportion of weeds in the grazed areas suggested that cattle consumed weeds as a part of their forage intake. Furthermore, although data are not presented here, when the areas for the clipping experiment were excluded after 3 yr of grazing activity, weeds began to grow and become noticeable.

Nutritive value

Grazing had little effect on forage quality perhaps due to the lack of effect on proportion of leaf and stem. The growth habit of WW-B. Dahl to remain vegetative until late summer likely diminished effects of defoliation strategies during May to July. Effects of grazing on CP were not observed even when leaves had consistently higher CP than stems in June and July which agrees with previous research (Hodgson, 1979; Minson, 1990; Buxton and Mertens, 1995; Barnes, *et al*., 2003). Differences in physiological maturity of the plants (time of sampling) did influence CP with a decline from 14 g $100g^{-1}$ in May to about 7 g 100 g^{-1} in June and July. This was consistent with declines observed in the clipping study as well. Protein concentration is higher in immature than in more mature forage (Hodgson, 1979; Minson, 1990; Buxton and Mertens, 1995; Barnes, *et al*., 2003). Concentrations of CP in this research agree with those found by Phillip (2004), but, are inconsistent with CP concentrations of 14% in June obtained by Niemann (2001, unpublished data, Texas Tech University) in New Deal TX, and CP concentrations of 5% reported by Sanderson *et al*., (1999), for central TX. Crude protein percentages at the end of the grazing season were still adequate to meet nutritional requirements of growing cattle. Crude protein percentages for May, June, and July from the clipping experiment of this research were lower than CP obtained in the same months from the grazing experiment. However, the decline was also observed, and was sustained through the growing season. Higher CP percentages were observed early in the growing season when the majority of the biomass being produced was leaf. Nitrogen fertilizer was applied in late August of each yr, which could have led to an increase on CP levels late in the season. This did in fact occur, but the increase was small and did not reach levels observed in May, likely because N fertilizer went to production of biomass diluting the effect. Philipp (2004) observed a similar effect of N fertilizer in CP concentrations. He reported an increase of CP following N fertilizer application in August, although, it did not reached levels obtained in May.

Neutral detergent fiber differences among grazing treatments in May are difficult to explain and are not accounted for by differences in either percentage dead material or in weed. Results for NDF in June and July were not affected by grazing activity. As in the case of CP concentrations, NDF is generally affected by morphological component and leaves have less NDF than stems (Hodgson, 1979; Minson, 1990; Buxton and Mertens, 1995). This was observed in our research but at this point the effect of maturity of the plants on morphology was not yet observed and biomass was largely leaf. In the clipping experiment an increase of NDF concentrations occurred in September consistent with increased maturity. Levels of NDF at the end of the season for this research were higher than values of 66.3 to 71.9% obtained in central TX (Sanderson *et al*, 1999); however, levels at the beginning of the season were similar to those found by Niemann (2001; unpublished data, Texas Tech University) in August. Neutral detergent fiber in June and July from the clipping experiment were slightly lower than percentages for the same months of the grazing experiment.

Concentrations of ADF, cellulose, and hemicellulose were not affected by grazing activity. Lignin content was only affected by grazing in July when non-grazed plants showed a higher concentration of lignin than grazed plants. Furthermore, ADF percentage was not dependent on the morphologic fraction although cellulose, hemicellulose, and lignin concentrations were. The fact that ADF concentration was similar in the leaf and stem fraction is inconsistent with theoretical assumptions in the sense that, as well as NDF, stems should have a higher ADF percentage than leaves. In this research, this increase was not observed. Moreover, when data for ADF, cellulose, hemicellulose, and lignin over the whole growing season were analyzed, there was no recognizable pattern that led to a clear interpretation of these components. As in the case of NDF, it was expected that the lowest levels of ADF, cellulose, hemicellulose and lignin would be found in plant material from early spring growth because of the low proportion of stems and structural carbohydrates at this stage of plant growth.

The pattern in ADF concentration throughout the season can be explained in part based on the cellulose and lignin patterns. In this case cellulose concentrations followed the expected trend of being higher in stems than leaves and tended to increase at the end of the season; however, lignin concentrations were higher in leaves than stems, at least in July, and had a tendency to decrease toward the end of the season, although the decline was not strong enough to be statistically significant. On the other hand, if the latter it is true, then NDF pattern should have been also affected, however, NDF fraction also includes hemicellulose, which presented a more defined pattern of increase along the end of the growing season. It is also possible that changes in NDF due to maturity occur sooner than changes in ADF. However, in order to explain the lack of grazing effect, differences in ADF, cellulose, and hemicellulose between morphological fractions are not enough. It is also possible that because grazing occurred at a time when plants were in full vegetative growth, maturity had not yet been reached. Additionally, ADF values obtained in this research are higher in comparison with those reported for Sanderson *et al*., (1999) and Philipp (2004).

Higher lignin concentration in plants of the non-grazed areas in July could be attributed to the increase in stem biomass in such areas. When attention is focused on the percentage of lignin, it is noticeable that they are high, although they agree with results obtained by Niemann (2001; unpublished data, Texas tech University).

The point is that all fiber components are correlated to each other and to estimate them is difficult if specific methodologies for each one are not followed. Crozier *et al*. (1997) reported irregular results pertaining to lignin for *B. caucasica* which might suggest that grasses from the genus *Bothriochloa* have different lignin composition than other grasses. When *B. caucasica* was fed to horses in a digestion trial, apparent lignin digestibility was negative indicating higher excretion than intake. This might be explained by differences in solubility in the acid detergent solution if lignin in the old world bluestems was more soluble than in fecal material. It at least raises the question of whether the standard ADF procedure adequately estimates lignin in *Bothriochloa* species.

Values for TNC obtained in this research do not agree with the 15% TNC obtained under grazing by Niemann (2001; unpublished data, Texas Tech University). The lack of difference between leaf and stem and the similarity of values over the growing season do not follow general patterns of behavior. Typically TNC concentration is higher in stems than leaves and is usually higher in cooler parts of the growing season.

Dry matter digestibility was also constant among grazing intervals and morphological components. It seems that grazing was not intensive enough to produce qualitative changes in forage. Along the growing season, it was not possible to differentiate a pattern on DMD. Values of DMD in both experiments were between 50 and 60% as expected. A likely explanation to the lack of DMD differences could be the fact that DMD is calculated from ADF values, and as it was discussed before, ADF did not show a recognizable nor expected behavior. Thus, it would be of value to estimate IVDMD by microbial digestion procedures.

Although leaves had in general higher quality than stems, except for ADF and TNC, differences in morphology, induced by grazing were not enough to produce differences in forage quality. This could suggest that age of the plant is more important than morphology explaining changes in quality.

Mineral concentration

In May, grazing had not been imposed since March and there were no differences in grazed vs. non-grazed forages in mineral concentration. This was of interest because these areas had been either grazed or non-grazed since 1997. Thus, in 6 yr, no detectable difference due to grazing had occurred. Under grazing, minerals are largely recycled while hay removal exports larger amounts of minerals. However, in the management imposed on this research, grazing vs. hay cutting did not appear to create a difference. Furthermore, supplementation of steers with 34 kg $steer^{-1}$ of a 4% CP cottonseed cake (Purina Mills, St. Louis, MO.) would contribute minerals to the pasture but did not make a detectable difference by yr 6.

Aluminum, Ca, S, Na, Cu, Fe, and Mn were higher in leaves than stems in June, however, the difference among plant components was not enough to influence differences among grazing treatments when stem mass increased in June, even, when the increase in mass stem was lower in grazed areas.

In July concentration of Fe did not differ statistically among plant components thus, it could be expected that no differences would occur among grazing treatments. However, these differences did occur, and non-grazed forage had lower Fe concentration than grazed plants. Grazing maintained plants in a more immature physiological stage, causing them to have higher levels of Fe; the effect of “aging” plants was not yet present. Furthermore, when results from the clipping experiment were compared, it was noticed that a decrease in concentrations of both Al and Fe occurred starting in July and continued through the rest of the season, which suggest that maturity of the plant is a factor influencing Fe levels in WW-B. Dahl and that grazing helps to delay the starting of the maturity stage. This could also be explained by soil contamination. Both Al and Fe increase in the presence of soil contamination and grazed plants may have been more susceptible to it than non-grazed plants.

The higher S concentration in non-grazed plants appears contradictory to concentrations in leaf and stem. With higher S concentration in leaves and a lower percentage of leaf in non-grazed forage, the higher S concentration in non-grazed forage is difficult to explain. Differences between grazed and non-grazed forage was small, however, S decreased with increase maturity. In the case of S it would be possible that the major impact in its concentration is given by the differential levels found in leaves and stems and not only due to maturity of the plants.

In general, leaves contain about twice as much Ca as stems; however, stage of growth has an inconsistent effect on Ca concentration (Minson, 1990). In the current experiment concentration of Ca was also higher in leaves than stems but did not reached a 50% difference. Calcium concentrations were similar in May, June and July in plants from the grazing experiment, and the concentrations are consistent with those for the same months in the clipping experiment.

In ruminant nutrition, a ratio of 1:1 to 7:1 for Ca:P is adequate if P is not deficient (NRC, 1996). In the current experiment Ca:P was at least 7:1 and P did not meet nutritional needs indicating that P supplementation would be needed by grazing steers. Selective grazing of leaves would increase this ratio further.

Manganese was higher in stems than leaves but that fact did not cause differences among grazing treatments in July. Throughout the growing season, Mn was relatively constant for the first 2 mo, with a slight decrease by mid-season and an increase toward the end of the season that coincided with the time of N fertilization.

In July, similar concentration of Na among grazing treatments can be related to similar concentration of Na in leaf and stem. This same pattern was observed throughout the season. Data from this research are in agreement with Minson (1990) who reported that there are no consistent differences in Na concentration regardless the morphological fraction analyzed or the age of the plants.

Concentration of Cu in leaves in June was higher than in leaves in July; while Cu in stems was similar for both months. Leaf can contain 30% more Cu than stem (Minson, 1990). Lower Cu in July could be due to age of the plants more than to its the effect of morphology. In June, Cu was higher in leaves than in stems and based on leaf and stem masses higher Cu could be expected to be higher in the treatment where the most leaf mass occurred. However, biomass increase is not only due to emergence of new material but to an increase in size and weigh of the material already present, thus, high Cu concentration of new leaf in the non-grazing treatment was likely neutralized by the low concentration of the aging stem. Additionally, in the grazed treatments, leaf and stem mass increases were due mostly to new material. In July, the lack of differences in Cu concentration among grazing treatments, could be attributed to removal of leaf by selective grazing. In this month, leaves still had higher Cu concentration than stems, but the difference between them was not as high as it was in June. Additionally, in the grazing treatments, biomass amounts did not increase but were maintained at the levels observed in June.

Higher Zn concentration in non-grazed areas in June and July may have been related to the high proportion of stem material. Concentration of Zn was higher in stems than in leaves. Higher Zn in stems was not expected and is contrary to results reported by Minson (1990). However, when Zn was examined in the soil (Chapter 2), extractable Zn was also high in non-grazed than grazed areas. The effect of grazing on Zn in both soils and plants justifies further research.

Similar concentration of Mg and P among grazing treatments corresponded to similar concentrations of these minerals in leaf and stem in June. Phosphorus and Mg were statistically higher in leaves than stems in July, but the actual difference among plant components was small and not enough to influence differences among grazing treatments. By July, K increased in leaf, which could have produced higher K concentration in non-grazed plants.

In general, mineral concentrations tend to decrease as plants matured, but this decrease responded also to changes in morphology associated to changes in age. It is not just a matter of time but also a matter of what happens, qualitatively, during that time which is driving changes in minerals. Mineral concentrations in forage are influenced by stage of growth and plant part (Minson, 1990). Grazing can alter the time of occurrence of qualitative changes.

Conclusions

Our results suggest that grazing intervals were not long enough to produce large changes in forage quality or mineral concentration, but some exceptions occurred. This was likely influenced by the growth habit of WW-B. Dahl with stem elongation late in the growing season. Thus, until September stem fractions would have contained a high percentage of leaf sheath rather than true stem. When the whole growing season was considered, some changes in forage quality and mineral levels were noticeable; however, there are still unclear effects that should be further investigated in order to understand use of WW-B. Dahl as a component in crop-livestock systems. In general, concentration of minerals declined over the growing season. Notable exceptions were Mg and Na which remained stable. Month by morphologic fraction was non-significant in this research for either minerals or quality components; however, this was only tested for the first 3 mo of the growing season and was tested at the same time than an effect of length of grazing was also tested. It would be advisable to carry out that separation into morphological fractions throughout the growing season, with no other objective than to determine forage quality and mineral concentration of each fraction.

Although leaves had, in general higher quality, except for ADF and TNC, differences in morphology, induced by grazing were not enough to produce differences of forage quality due to grazing. This could lead one to think that, age of the plant is more important than morphology in explaining changes in quality.

For some minerals, morphologic fractions have different mineral concentrations, but differences in magnitude among them were not big enough to demonstrate differences when proportion of morphological fractions change. Zinc appeared to be an exception and a higher concentration in stem appeared to partly explain higher Zn in non-grazed forage but effects of grazing on soil Zn also appeared to explain the difference.

Our results also suggest that WW-B. Dahl can provide forage for both hay and grazing and would meet nutritional needs of most beef cattle although supplementation with CP and minerals, particularly P, S, Cu and Mn, may be required. It is important to note that, when researchers report results, often they do not mention when or where they were obtained. Just analyzing growth occurring during the summer may not adequately describe nutritive value in the case of WW-B. Dahl. After 5 yr of grazing vs. hay cut and removal, there was no evidence of consistent differences in plant mineral status with the possible exception of Zn that appears to be declining under grazing, as opposed to hay harvesting. However, shifts in Zn concentration could also be explained by changes in morphology and further research is needed to define these effects.

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CHAPTER IV

ECONOMIC ANALYSIS OF AN INTEGRATED CROP-LIVESTOCK SYSTEM ON THE TEXAS HIGH PLAINS

Abstract

Integrated crop-livestock systems are an alternative to monoculture systems due to the decrease in input use including irrigation water and a higher intensity of land use. There is a great amount of agronomic evidence that crop-livestock systems have a lower negative impact on the environment but to fully asses their feasibility to potentially replace monoculture systems in the Texas High Plains their economic profitability must be evaluated. Four scenarios were simulated for the years 1998 to 2004 in two systems established in the Texas High Plains to compare a cotton (*Gossypium hirsutum* L.) monoculture system using management practices recommended by the Texas Cooperative Extension Service and an integrated crop-livestock system for production of cotton and feedlot ready stocker steers that included WW-B. Dahl [*Bothriochloa bladhii* (Retz.), S.T. Blake]. as a perennial forage and rye (*Secale cereale* L.) and wheat (*Triticum aestivum* L.) in alternate yearly rotation with cotton for grazing by steers. Favorable scenarios for both systems were increased yields and decreased variable costs with the higher returns in the integrated crop-livestock system. Cotton produced under the monoculture system

and cotton produced in the integrated system achieved similar results regarding yields and input use. Livestock produced in the integrated system is an advantage because of the possibility to obtain revenue without significantly increasing the overall fixed cost of the system.

Introduction

Crop-livestock systems are being considered around the world as a possible alternative to satisfy the demand for agricultural products. However, the reasoning behind the adoption of these types of production systems varies depending on environmental and socioeconomic conditions of the place where they would be established. In Sub-Saharan Africa, crop-livestock systems are viewed as a way of expansion and intensification of agriculture as opposed to the low input/output modes currently in place (Powell *et al*., 2004). In regions of highly intensive high input/output agriculture, as the Texas High plains, where cotton is the primary crop, but where also sorghum and wheat are intensively produced, crop-livestock systems are considered an alternative to lessen problems caused and faced for this intensity.

In general, monoculture systems in the Texas High Plains have a high degree of sophistication and technology use that make them highly profitable but at the same time, these conditions of production have a narrow margin of adaptation and action against any unfavorable conditions that could arise during the growing season, therefore, challenging profitability. One course of action that has been used to overcome the problems faced by monoculture production is the dependence of these systems in external aid, including subsidies, economic incentives, and insurance programs that assure income to producers. However, in recent years, these external aid schemes have proven not to be an adequate strategy.

The nature of monoculture production makes these systems fragile and susceptible to any changes in environmental conditions. The main problem being the vicious circle occasioned between environmental damage caused by the production activity by itself and the susceptibility of it to that environmental damage. Furthermore, additional disadvantages for monoculture systems are the growing irrigation water scarcity and the restriction of land use. Only one harvest can be obtained in a given year. Approaches to solve some of the problems faced by monoculture production are the improving of irrigation technology with LEPA and sub-surface irrigation systems, the development of the concept of precision agriculture that identifies specific places of input application within a field and the use of genetically improved crop varieties, and the adoption of alternative production systems, among others.

In the afore mentioned perspective, integrated crop-livestock systems are an alternative to monoculture systems due to the decrease in input use including irrigation water and a higher intensity of land use. There is a great amount of agronomic evidence that crop-livestock systems have a lower negative impact on the environment but to fully prove their feasibility to replace monoculture systems in the Texas High Plains their economic profitability must be evaluated.

Allen *et al.*, (2005) showed higher profitability of an integrated crop-livestock system than a cotton monoculture over a period of 4 yr in New Deal, TX. Furthermore, difference in profitability became even greater when depth to water increased.

The objective of this study was to compare the economic profitability of both a cotton monoculture and an integrated crop-livestock system established in the Texas High Plains.

Materials and methods

In 1997, two systems were established to compare a cotton monoculture system using management practices recommended by the Texas Cooperative Extension Service and an integrated crop-livestock system for production of cotton and feedlot ready stocker steers that included WW-B. Dahl [*Bothriochloa bladhii* (Retz.), S.T. Blake]. as a perennial forage and rye (*Secale cereale* L.) and wheat (*Triticum aestivum* L.) in alternate yearly rotation with cotton for grazing by steers (Allen *et al*, 2005). The cotton monoculture and the integrated crop-livestock system were established in the Northeast Lubbock County Plant Stress Field Laboratory of the Department of Plant and Soils Science of Texas Tech University. A thorough description of these two systems was provided in Chapter 2 and can also be consulted in Allen *et al*. (2005).

Although both systems started in 1997, grazing did not occur until 1998, thus, the economic analysis was conducted on data from 1998 to 2004. Detailed yearly records on input use, production practices, yields, and prices of both inputs and outputs were used to construct standard economic budgets for both systems that included per hectare variable (VC), fixed (FC), and total (TC) costs of production, and gross revenues (R). Two estimates of profitability were calculated: net returns above variable costs (NRVC) and net returns above total costs (NRTC). Economic budgets for the rye-cotton-wheat and wheat-fallow-rye rotations, WW-B. Dahl perennial pasture and livestock components of the integrated crop-livestock system were calculated individually and were used to calculate per hectare VC, FC, TC, R, NRVC, and NRTC for the integrated crop-livestock system. Small grain-cotton rotations represented 47% (23.5% each rotation) and WW-B. Dahl perennial pasture represented 53% of the integrated crop-livestock system. Livestock per hectare VC, FC, and TC were added to the values previously calculated for the forage components of the integrated system because steers grazed the entire integrated crop-livestock system area.

Outputs produced in the cotton monoculture system were cotton lint and cotton seed, and outputs produced in the integrated system were cotton lint, cotton seed, WW-B. Dahl seed and 670 kg feedlot ready stocker steers (Table 4.1). Variable costs included the cost of all pre-harvest and harvest inputs used, as well as, other costs associated with the application of these inputs. Fixed costs involved the costs associated with ownership of machinery and equipment, irrigation system, and land charges. Irrigation system costs assumed the installation of a sub-surface drip irrigation system. The cost of the irrigation system was made up for a representative 48.5 ha in the Texas High Plains. Although there is a high variability of pumping-lift in use in this region, a pumping depth of 45 m was used in the construction of budgets for this research. Details on the economic analysis are shown in Allen *et al*., (2005).

Average VC, FC, TC, R, NRVC, and NRTC for the 6 yr (Table 4.2-4.3) of both systems were considered as the baseline to be compared with increases or decreases of the magnitude of two times the standard deviation of yields or variable costs. Variations on yields and variable costs were conducted independently, while all other factors were held at baseline level, thus, four scenarios were estimated: increase or decrease of yields and increase or decrease of variable costs.

Table 4.1. Prices and yields per hectare of outputs produced in a cotton monoculture and an integrated crop-livestock system that included a WW-B. Dahl perennial pasture, a rye-cotton-wheat and a wheat-fallow-rye rotation averaged across years 1998 to 2004 in New Deal, TX.

		Cotton monoculture	Alternative system
Product	Price, $	Yield, kg ha^{-1} system component^{-1}	
Cotton lint	1.2 kg^{-1}	1219.5	292.9
Cottonseed	0.1 kg^{-1}	1815.2	435.9
WW-B. Dahl seed	39.8 kg^{-1} PLS †	-	13.6
Stocker steers	1.9 kg^{-1} LW‡	-	668.0

† Pure live seed (PLS)

‡ Live weight (LW)

Table 4.2. Prices and yields per hectare of outputs produced in an integrated crop-livestock system that included a WW-B. Dahl perennial pasture, a rye-cotton-wheat and a wheat-fallow-rye rotation averaged across years 1998 to 2004 in New Deal, TX.

		System component			
		Rotation			
		Rye-cotton-wheat	Wheat-fallow-rye	WW-B. Dahl perennial pasture	Livestock
Product	Price, $	Yield, kg ha^{-1} system component			
Cotton lint	1.2 kg^{-1}	1246.4			
Cottonseed	0.1 kg^{-1}	1855.2			
WW-B. Dahl seed	39.8 kg^{-1} PLS †			25.7	
Stocker steers	1.9 kg^{-1} LW‡				668.0

† Pure live seed (PLS)

‡ Live weight (LW)

Table 4.3. Gross revenue, costs of production, and net returns of a cotton monoculture and an integrated crop-livestock system that included a WW-B. Dahl perennial pasture, a rye-cotton-wheat and a wheat-fallow-rye rotation averaged across years 1998 to 2004 in New Deal, TX.

	System	
	Cotton monoculture	Integrated crop-livestock system
	$\$ ha^{-1}$	
Gross revenue	1698.1	2264.1
Cotton lint	1478.1	354.5
Cottonseed	220.0	52.7
Hay	0.0	4.6
WW-B. Dahl seed	0.0	570.9
Stocker steers	0.0	1281.2
Variable cost	1146.8	1785.2
Delivery	0.0	8.8
Stocker Steers	0.0	846.8
Hay	0.0	11.0
Feed - crude protein	0.0	11.8
Labor and miscellaneous	0.0	29.6
Salt and Minerals	0.0	6.1
Vet. & Processing	0.0	13.1
Interest - OC Borrowed	0.0	9.9
Interest - OC Equity	0.0	20.1

Table 4.3. Continued.

	System	
	Cotton monoculture	Integrated crop-livestock system
	$ ha-1	
Pre-harvest cost	674.2	284.1
Seed - cotton	69.1	16.2
Seed Treatment	28.8	6.7
Seed - wheat	12.8	9.1
Seed - Rye	0.0	7.6
Herbicide	122.2	44.9
Fertilizer	81.4	55.5
Crop Insurance	49.4	11.6
Insecticide	38.8	9.1
Hoeing & Spot Spraying	5.7	2.5
Machinery	145.5	35.9
Irrigation	115.7	84.6
Harvest cost	439.4	529.7
Harvest Aid	58.7	16.0
Strip & Module	179.1	42.9
Ginning	201.5	48.3
Custom baling & hauling	0.0	1.0
Custom seed harvesting	0.0	421.3
Interest - OC capital	33.7	14.2
Interest positive cash	-0.5	-0.2

Table 4.3. Continued.

	System	
	Cotton monoculture	Integrated crop-livestock system
	$ ha-1	
Fixed cost	740.8	632.3
Machinery and equipment	151.5	43.0
Irrigation	490.5	490.5
Land	98.8	98.8
Total cost	1887.6	2417.6
Net return above variable cost	551.2	478.9
Net return above all costs	-189.5	-153.5

Results and discussion

Over the period 1998-2004, net returns above variable costs were positive for both systems and the cotton monoculture had about $70.00 more per hectare than the integrated system, which represents a 15% increase in profitability. Both cotton monoculture and the integrated crop-livestock system were not profitable, when compared in terms of their net returns above total costs (Table 4.4); however, the integrated system lost less money than cotton monoculture. This seems to be a contradiction, it could be expected that the integrated system would continue to have lower net returns when the fixed costs were incorporated to the analysis, however, fixed costs for the integrated system accounted for 26% of the total costs while they accounted for 39% of the total costs of cotton monoculture production.

Allen *et al*. (2005) reported an opposite tendency in net returns above variable costs for the first 4 yr of these two systems. They calculated net returns above variable costs to be $143.00 higher for the integrated system than for cotton monoculture at the pumping depth of 45 m, as in the case of the current research. The reason for this difference could be attributed to the inconsistency of seed production of WW-B. Dahl. Furthermore, for the 1999-2000 and 2003-2004 growing seasons no seed were harvested. Additionally, when the integrated system was disaggregated by system component the rotation wheat-fallow-rye had negative net returns above variable costs, which helped to explain the lower net returns above variable costs for the integrated system (data not shown). The three crop components had negative net returns above total costs but the livestock component net returns above both variable and total costs were positive.

With increased output yields, gross revenue of the integrated system increased 75% with respect to the baseline while gross income for cotton monoculture only increased 60%. This increase in gross revenue caused an increase of net returns above variable costs of 4 and 3 times with respect to the 6 yr average in the integrated system and cotton monoculture, respectively, and an increase of net revenues above total costs of 10 and 4 times for the integrated system and cotton monoculture, respectively. The integrated system had the highest net returns with differences of $630.00 and $741.00 with respect to the net returns of cotton monoculture when calculated above variable and total costs, respectively. The difference in net returns above total costs is higher because of the proportionally lower total cost in the integrated system with respect to cotton monoculture. When analyzed by system component, the pattern observed in the average returns above variable costs still hold. Furthermore, net returns above total costs were positive for all components except wheat-fallow-rye rotation had negative returns.

When yields were decreased, gross revenue decreased 48% and 59% with respect to the baseline for the integrated system and cotton monoculture, respectively, which caused a decrease in net returns above variable costs of 128% and 81% for the integrated system and cotton monoculture, respectively. With this proportional changes cotton monoculture appeared to lose less money than the integrated system. Cotton monoculture lost $170.00 less than the integrated system when net returns were calculated above variable costs and lost $60.00 less when net returns were calculated above total costs. Analysis by system component showed negative returns for all 3 crop components and positive returns for livestock component.

The increase in variable cost with respect to the baseline of the integrated system was 59% and in cotton monoculture was 38%. These increases in variable costs produced increases on the total cost with respect to the baseline of 44 and 18% for the integrated system and cotton monoculture, respectively. With these increases, net returns above variable costs of the cotton monoculture were positive while they were negative for the integrated system, with a difference between both systems of almost $790.00. In terms of net revenues above total cost, both systems are non-profitable, with the integrated system losing twice as much money as the cotton monoculture. Wheat-fallow-rotation and WW-B. Dahl perennial pasture components also had negative net returns above variable costs, while rye-cotton-wheat and livestock had positive net returns above variable costs. Only livestock showed positive net returns above total cost.

Variable costs with respect to the baseline decreased 45 and 30% for the integrated system and cotton monoculture, respectively. When VC were decreased, both systems had positive net returns, and the integrated system showed the higher gains. The difference in net returns above variable costs between the integrated system and cotton monoculture was $390, and the difference in net returns above total costs was $502.00. In this case, also the wheat-fallow-cotton was the integrated system component with negative returns.

Favorable scenarios for the integrated system and cotton monoculture were when the yields were increased and when VC were decreased. Additionally, in both cases the proportion of increase or decrease were higher in the integrated system than in cotton monoculture, thus, producing higher returns in the former. However, the individual participation of each component does not seem to vary among the four scenarios with respect to the pattern identified with the original data. Furthermore, loses and gains on net revenues for the rye-cotton-wheat rotation were almost identical to those for cotton monoculture in all four scenarios because the budget regarding this component was constructed in such a way that only revenues and costs for cotton were analyzed. Revenues and costs of rye were charged to the wheat-fallow-rye rotation which explained the consistently negative returns of this component. In the same line of thought, positive net returns obtained in the livestock components are derived from the fact that no fixed costs are included in its budget; fixed costs were proportionally distributed only among the crops.

Cotton monoculture and cotton in the integrated system produced similar results regarding yields and input use and, therefore, in net returns. Livestock is a plus for the system because with the same fixed cost used to produce the crops and the forages it was possible to obtain revenue from livestock.

Table 4.4. Gross revenue, costs of production, and net returns of a cotton monoculture and an integrated crop-livestock system that included a WW-B. Dahl perennial pasture, a rye-cotton-wheat and a wheat-fallow-rye rotation averaged across years 1998 to 2004 in New Deal, TX.

		Yields		Variable costs	
System	1998-2004 avg.	Increased	Decreased	Increased	Decreased
	$ ha^{-1}				
Cotton monoculture					
Gross Income	1,698.06	2,695.13	700.99	1,698.06	1,698.06
Per hectare variable cost	1,146.80	1,146.80	1,146.80	1,488.34	805.25
Per hectare fixed cost	740.82	740.82	740.82	740.82	740.82
Per hectare total cost	1,887.62	1,887.62	1,887.62	2,229.17	1,546.08
Net return above variable cost	551.26	1,548.33	(445.81)	209.71	892.80
Net return above all costs	(189.56)	807.51	(1,186.64)	(531.11)	151.98
Integrated crop-livestock					
Gross Income	2,264.34	3,966.11	1,169.82	2,262.80	2,262.80
Per hectare variable cost	1,785.03	1,785.03	1,785.03	2,840.61	975.85
Per hectare fixed cost	632.33	632.33	632.33	632.33	632.33
Per hectare total cost	2,417.36	2,417.36	2,417.36	3,472.94	1,608.17
Net return above variable cost	479.30	2,181.08	(615.21)	(577.82)	1,286.95
Net return above all costs	(153.02)	1,548.76	(1,247.54)	(1,210.14)	654.63

Conclusions

Favorable scenarios for the integrated system and cotton monoculture were when the yields were increased and when VC were decreased; both scenarios produced higher net returns in the integrated system than in cotton monoculture.

The individual participation of each component does not seem to vary among the four scenarios with respect to the pattern identified with the original data. Livestock component of the alternative system had consistently positive net returns, while wheat-fallow-rye rotation had consistently negative returns. WW-B. Dahl net returns above variable costs were positive, while net returns above total cost were negative. The same occurred with net returns of rye-cotton-wheat rotation. Furthermore, rye-cotton-wheat net returns varied similarly to net returns of cotton monoculture,

Because of the way the budgets were constructed, it would be more accurate to say that in reality what was analyzed was cotton in the integrated system and a small grain-fallow rotation. Cotton monoculture and cotton in the integrated system produced similar results regarding yields and input use and, therefore, in net returns.

Livestock is an advantage for the integrated system because it is possible to obtain revenue from it without increasing the fixed cost of the system.

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CHAPTER V

OVERALL DISCUSSION AND IMPLICATIONS

Discussion

Usually, research in soil minerals under productive circumstances has been made from the perspective of plant nutrition and impact on yields, and to a much lesser extent regarding effects on animal production. However, the ability of soil to provide nutrients required by plants is a chemical soil property, thus, aside from measured plant-response differences, soil fertility variations can best be characterized through chemical examination of the soil (Sims, 1991; Harter, 1991). Availability of micronutrients to plants is often poorly related to the total quantity of the particular element in the soil (Moraghan and Mascagni, 1991). Changes in the environment often have a greater effect on micronutrient than on macronutrient nutrition of plants.

Mineral determination in the current research was done as a first step to understanding how minerals vary in the soil, as influenced by grazing or by a systems approach. Our results showed minerals in the soil were in general, present within the normal ranges needed for plant production, with the exception of N and P, which were provided through fertilizer applications. However, when mineral status was measured at the plant level, results of the current research suggest that WW-B. Dahl would likely fail to meet beef cattle mineral requirements, specifically P, S, Cu and Mn. It seems that availability of minerals from the soil to the plant was at an adequate level to assure plant production but was not enough to guarantee livestock requirements. The mineral status of soils and WW-B. Dahl plants was consistent in both non-grazed and grazed areas, with exception of Zn which was lower in soils and plants of grazed than non-grazed areas.

There is still a great amount of uncertainty among the processes occurring at soil and plant level regarding mineral cycles. Plants require minerals to growth adequately, but amount needed by them do not necessarily assure plants would become a good source of minerals for livestock. It is not enough for minerals to be present in the system but they must also be bioavailable to both plants and animals. Therefore, soil fertility should aim at providing adequate nutrients to the plant for optimum plant growth and if the livestock requirements are not met, then mineral supplementation can be provided. However, mineral supplementation will depend on what mineral is deficient. In the case of sulphur it is more effective to fertilize the plant because of the effects of S on dry matter digestibility, lignification, and utilization of crude protein by the animal. Direct supplementation to the animal has not been as effective.

After 5 yr of grazing vs. hay cut and removal, there was no evidence of consistent differences in plant mineral status with the possible exception of Zn that was lower under grazing, as opposed to hay harvesting. Our results also suggest that WW-B. Dahl can provide forage for both hay and grazing and would meet nutritional needs of most beef cattle although supplementation with CP and several minerals may be required.

The integrated system showed a lower loss of money than the cotton monoculture over the 6 yr period that both systems have been in place. Furthermore, it is important to highlight that this lower level of loss was obtained considering the fact that WW-B. Dahl seed was not harvested in 2 out of the 6 yr analyzed. Economic analysis of the integrated system showed that the contribution of each component did not vary among different scenarios with respect to the pattern identified with the original data. Our results showed that in favorable conditions such as with increased yields or decreased costs of production, the integrated system had greater profitability than cotton as a monoculture.

Cotton monoculture and cotton in the integrated system produced similar results regarding yields and input use, and therefore in net returns although the impact of cotton production in the system was diluted because it was only produced in 23% of the area in any given yr. However, the livestock component of the alternative system offers the advantage of being an additional source of income without significantly increasing the fixed costs already used to produce other outputs.

Implications

Evidence attained in this research suggests that integrated crop-livestock systems could be considered a successful alternative for cotton monoculture in the Texas High Plains. WW-B. Dahl was shown to be a good source of forage for steers in terms of forage production and nutritive value, although mineral and CP supplementation is likely to be required.

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