CHAPTER I

Introduction

Madiama commune is located in the extreme northern portion of the north-Soudanien, near the south Sahelian, between 14° and 16°N latitude. This zone is characterized by a short rainy season (4 months) from May-June to September-October, with rainfall varying between 200 and 600 mm, and a long dry season (DRSPR/Mopti, 1992). The length of the agricultural season is 80 to 90 days with 41 wet days. Madiama commune lies in the Delta of Niger region on the plateau of Bandiagara-Hombori. The commune is comprised of 11 villages totaling 22,000 inhabitants. The soil type in this region is sandy and sandy-loam, with quartz appearing at a depth of 50 to 70 cm, and with an associated herbaceous layer dominated by annual plants. These soils are characterized by low fertility and low soil water retention.

The lack of pasture and forage resources has been a growing problem in the Sahel region of sub-Sahara Africa. Demographic growth, extensive row cropping, increasing herd size, high levels of exploitation of woody resources, and climatic fluctuations have all contributed to serious losses of plant biodiversity within this region. In addition, utilization of pastureland resources has become a major source of conflict among stakeholders. Grazing season length decreases from south to north as influenced by annual rainfall, which affects plant community yield and quality. The number and distribution of perennial species, herbaceous as well as woody, and annual species has decreased over time limiting forage utilization (Penning de Vries et al, 1991). Breman and Cisse (1977) discussed the influence of drought and grazing on herbage composition and coverage. Breman and Cisse, (1997) concluded that grazing stimulated legumes with short growth cycles such as *Zornia glochidiata* and the small annual grass *Microchloa indica*. According to Breman and Cisse (1977), the disappearance of the relatively good fodder grasses such as the perennial grass *Andropogon gayanus* is one of the most striking effects of drought and grazing. Annual grasses and other species of low forage quality severely limit potential animal production. The replacement of perennial tall grasses by short cycle annual grasses and forbs means an important change in the nutritive value of available forage. Annual plants with very short cycles mature faster and therefore become undesirable. Perennial forages in Madiama have become nearly non-existent, annual grasses and some legumes have become the dominant species in pastures. Seasonal movement of animals (Transhumant practices) is also increasingly limited, particularly in traditionally utilized pastoral areas of the commune, resulting in overpopulation of animals and overgrazing. The existing low level of plant succession under the current management system as resulted in a severe botanical shift; weedy annual species dominate pastures. As a result, pasture and livestock productivity has declined leaving the community with little food and increasing poverty.

Identifying plants that persist in such environments is a key factor that will help understand pasture ecology in Madiama (and thus in the Sahel) and better manage this land. A grazing experiment will provide important data on the botanical composition and potential natural reseeding of these pastures under various pressures. Burrows (1991) states that more attention is needed in natural pastures to define what are the appropriate stocking rate and grazing pressure to maintain these pasture systems. Some of the questions raised by Burrows (1991) include identifying ‘indicator plants' whose presence in a pasture is symptomatic of overgrazing or under use. In the case of Madiama, the presence of invasive specie like *Cassia tora* can be considered as an indicator of overgrazing and land degradation. *Cassia tora* (sickle pod) is an annual leguminous plant widely known in the United States as a noxious weed mostly found in soybean fields. Cassia has high nutritive values such as protein compared with most of the forage species found in the area. However, due to its aggressive nature that excludes grasses from being grown with it or in the surrounding areas, and its unpalatability to animals, it imposes more problems than potential benefits. *Cassia tora*, if managed, could improve pasture productivity by providing more litter and increasing organic matter in the soil as well as recycling essential nutrients. It could also provide a source of feed during the dry season when used as silage.

Low soil fertility, particularly N and P deficiency, is one of the major constraints of African agriculture (FAO, 1971; DeWit, 1981; Penning de Vries & Djiteye, 1982; Mokwunye et al., 1996). The vast majority of Malian farmers lack access to commercial fertilizers. Alternative approaches to improve soil fertility and productivity will benefit Malian farmers as well as other West African countries with similar soil and environmental conditions. Low P availability in tropical acid soils often results from the fixation of P by Al and Fe in soil. Generally, Al and Fe-phosphates are relatively unavailable to plants; however, some legumes are able to utilize unavailable P (Ae et al., 1990). Identifying such legumes would be useful for maintaining productivity without further addition of fertilizer P and N (Sanchez and Salinas, 1981). Quantitative information on *Cassia*'s ability to cope with low P environments is unavailable. Experiments are needed to characterize the growth mechanisms of *Cassia tora* under various soil P levels and to examine which sources of P *Cassia* utilizes best.

The overall focus of this research was to increase forage resources through better pasture management practices and better understanding of the ecological system through the identification and exploitation of a single plant, *Cassia tora*. Three experiments were conducted with the following specific objectives:

1- Controlled grazing: botanical response, biomass productivity and animal performance; the objectives of this experiment were: (1) to determine the influence of the tethered grazing method on biomass productivity and plant diversity; and (2) to evaluate animal performance in terms of weight gains under tethered grazing.

2- Dry season feed supplements: the potential role of *Cassia tora*. The objectives of this experiment were: (1) to evaluate the chemical characteristics (crude protein, *in vitro* dry matter digestibility, fiber, etc.) of ensiled vs. fresh *Cassia tora*; and (2) to examine the effects of additives (water or honey) and other forages (grasses) on the quality of the ensiled material.

3- Influence of phosphorus sources and rates on uptake by *Cassia tora*. The objectives of this experiment were: (1) to determine the potential of *C. tora* in extracting soil P; (2) *Cassia* response to various sources of P; (3) *Cassia* response to different levels of added P in the soil.

CHAPTER II

Literature Review

About the Sahel

The Sahel region of Africa is an ecological zone comprising various climatic and vegetation zones extending from the Atlantic coast of West Africa to the Sudan (Fig. 2.1) (Ridder *et al.*, 1982). There are several ways to define these zones, and often they are distinguished according to isohyets. Boudet (1975, as cited by Ridder *et al.*, 1982) used the following classification:

- The subdesert Sahel, characterized by a Sahara-like desert climate, with annual rainfall of less than 200 mm, with almost no active period of grazing. The 200 mm isohyet roughly corresponds to the southern border of this region.
- The typical Sahel is characterized by a subdesert, Sahelo-Saharan climate with 2 to 2 1/2 months of rainy season averaging from 200 mm in the north to 400 mm in the south. The active grazing period in the typical Sahel is about one month (August).
- The Sahelo-Sudanese region is characterized by a dry tropical climate with an annual rainfall ranging from 400 mm in the north to 500-600 mm in the south. The active grazing period in this part of the Sahel is about three months.

The southern boundary of the Sahelo-Sudanese zone corresponds approximately to the 550 mm isohyet. This part of the Sahel is where our experimental sites are located (Mopti). According to Boudet's (1975) classification, the 100 mm and 600 mm isohyets of average rainfall demarcate the Sahel, which is bounded on the north by a transitional zone to the Sahara and on the south by a transitional zone to the Sudan region, with more rainfall (Fig. 2.2) (Ridder *et al*., 1982).

Our experimental site, the Madiama commune (region of Mopti) is located in the extreme northern portion of the north-Soudanien, almost into the south Sahelian, between 14° and 16°N latitude and therefore falls between the 200 mm and 600 mm isohyets and between typical Sahel and Sahelo-Sudanese border.

Climate of the Sahel

As previously discussed, the Sahel region falls between 13ºN, with an average rainfall of 600 mm, and 17ºN, with 100 mm rainfall. This region is characterized by 2 to 4 months of rainy season followed by a long dry season. Precipitation in this region exceeds evapotranspiration only during the short wet season (Fig. 2.3).

Pedology of the Sahel

The action of rainfall is influenced by parent material and topography. Most of the Sahel regions exhibit a series of depressions (synclines) that have filled up with erosion products (Ridder *et al*., 1982). Most of the deposits are a result of sandy, loamy, or clay sediments. The majority of the soils found in the Sahel are sandy with an eolian origin (wind erosion); the sandy soil regions are separated by numerous loamy-clay depressions (Penning de Vries and Djiteye, 1991). The soil distribution is related to the topography; sandy dunes form the elevated part of the topography, depressions of loamy-clay form the low topography, and in between, loamy or sandy-loam soils are formed. The water flows into depressions and form temporary flood areas. Climate is another important factor in soil formation, and the extremely wet season in the tropics promotes deep weathering, but the extended dry season in the Sahel accelerates irreversible oxidation of aluminum and iron hydroxides (Tardy, 1992; Tardy and Roquin, 1992; Bloom, 1998). Within a few years, the soils harden and form what is called *laterites*; in sub-Saharan western Africa, hardened laterites may cover 2.5 million km^2 (Lal, 1987 as cited by Bloom, 1998). This accumulation of iron and aluminum minerals results in a hard laterite (hardpan) causing bare stretches (segments of denuded land with no vegetative cover). These physical characteristics of the soil are associated with the chemistry of the soil and result in poor soil fertility. Soil fertility will be discussed in relation to plants later in this chapter.

Vegetation of the Sahel

Vegetation is a function of its substrate and diversifies as a function of both soil and topography. Topography and soil texture dictates the amount of water available for plants. The variation in soil texture and topography is reflected in biomass production, and relative abundance and diversity of the vegetation found in the region. Sand dunes have good infiltration but low water holding capacity, and slopes allow for runoff, resulting in open vegetation (or sparse vegetation). The herbaceous vegetation layer on sand dunes can be considerable, consisting mainly of annual grasses (Ridder *et al*., 1982). Woody species as well as perennial grasses develop on the loamy clay depressions. Bare strips characterize the slopes between sand dunes and loamy clay depressions**.** The Sahel is mostly covered by steppes, composed of mostly short annual grasses with some herbaceous vegetation, including perennial grasses and occasional woody species (Penning de Vries and Djiteye, 1991). In the Sahel region, north to south, the height and the density of trees increase. The various vegetation zones of Mali are illustrated in Fig. 2.4; the Sahel region falls in the middle and includes the region of Mopti and the Central Delta of Niger flood zone.

Madiama commune is located in the extreme northern portion of the north-Soudanien, almost into the south Sahelian, between 14° and 16°N latitude. This zone is characterized by a short rainy season (4 months) from May-June to September-October, with rainfall varying between 200 and 600 mm, followed by a long dry season (DRSPR/Mopti, 1992). The length of the cropping/pasturing season is 80 to 90 days with 41 wet days. Madiama lies essentially on the region of the Delta of Niger and on the plateau of Bandiagara-Hombori. The commune covers an area of 16,700 ha, and has a population of 21,871 comprising people of various ethnic groups. The dominant ethnic groups are Bambara, Marka and Peule. Field crops and livestock are the dominant agricultural production systems, which contribute 46.2% and 34.4% of the community income, respectively (Kabore, 2001). Assarki (2000) documented significant acreage of agronomic and horticultural crops, such as *Pennisetum glaucum* (millet), *Sorghum bicolor* (sorghum), *Citrullus lanatus* (watermelon), *Arachis* L. (groundnut), *Vigna unguiculata* L. (niébé), *Sesamum indicum* (sesame), *Hibiscus esculentus* (gombo), and *Oryza sativa* (rice) in the flooded low lands. The pastureland covers 1172.5 ha in the non-flooded zones and 800 ha in the flooded basins (Badini and Dioni, 2000), totaling 1972.5 ha of pasture, which represents less than 20% of the total area of the Madiama commune. Pasture management practices are needed to improve pastoral resources and its utilization.

Dynamics of Sahelian pastures

It is important to understand the dynamics of Sahelian vegetation in order to better manage the pastures in this region. Penning de Vries and Djiteye (1991) stated that human pressure is the most determinant evolution factor in the Sahel. Cultivation replaces natural vegetation, grazing pressure is concentrated on smaller areas, and less animal movement occurs in this region. However, climatic fluctuation and the recent droughts of the 70's have also contributed to changes in vegetation in the past three decades. Breman and Cisse (1977) have studied the dynamics of the vegetation in the transition zone from the savanna (south of Sahel) to the Sahel and were able to distinguish between the influence of drought and the influence of overgrazing. The area of study was a protected ranch located in the Niono region in the Central Delta of the Niger; this region is flooded during the wet season. The soils are mostly sandy (sand dune dunes) and loamy (in the plains). The vegetation had been described prior the serious drought in 1969 by previous investigators. Three main vegetation types were distinguished (Boudet, 1970 as cited by Breman and Cisse, 1977):

- The legume tree *Pterocarpus lucens* characterizes clay depressions and the large loamy plains with other woody species in a relatively open savanna.
- Tall perennial grass, *Andropogon gayanus* characterizes the depressions and valleys between the sand dunes.
- *Schoenefeldia gracilis* was the most important grass in the eroded sand dunes.

Breman and Cisse (1977) studied 8340 ha of the 11000 ha area previously studied by Boudet (1970) and assessed the effect of drought from 1970 to 1977 based on Boudet's initial study.

The species composition and the percentage coverage were studied in September, at the end of the growing season. The percentage vegetative cover at the end of the growing season was measured by estimating the surface of the vertical projection of the vegetation over the total surface of the selected strips of 10 X 0.1 m. Species composition was estimated visually, indicating the relative abundance and frequency per species. Intensive grazing pressure was characterized by high animal pressure within 4 km of the permanent water point.

The effect of the drought on different species was more pronounced at the northern limit of their habitat, and the species in regression were replaced by 77% invader species, like *Borreria* spp (Fig. 2.5). Grazing affected fodder grasses like *Andropogon gayanus*, which was replaced by a legume with a short growing cycle, *Zornia glochidiata*, representing 59% of the species. Additionally, grazing caused an increase of unpalatable species such as Elionurus elegans by 21 %.

The effect of severe drought caused a shift in the Sahelo-soudanien (south of Sahel) vegetation in the direction of Sahelian vegetation. On the other hand, savanna species and certain species of the transition zone between the savanna and the Sahel that have disappeared were replaced almost entirely by invaders rather than true Sahelian species with a more northern habitat. The effect of grazing stimulated a legume with a short growth cycle, *Zornia glochidiata* and annual grasses such as *Elionurus elegans* and *Microchloa indica*. Both drought conditions and grazing pressure may have caused the disappearance of desirable/palatable fodder grasses such as the perennial grass *Andropogon gayanus*. Intensive and continuous grazing may adversely affect seed production of preferred species and favor unpalatable species like *Cassia tora* (Breman et al, 1979/80). Hiernaux (1996) suggested that heavy grazing did not have a pronounced effect on biomass production but caused a shift in floristic composition toward less palatable species. This effect was observed where stocking rates were extremely high within a few hundreds meters of water point or herd rest area. Hiernaux (1996) also found that long term heavy grazing during the growing season often resulted in an increase in the population of dicotyledons, such as *Zornia glochidiata*, *Tribulus terrestris*, *Cassia mimosoides*, and annual grasses such as *Eragrostis pilosa*; these findings are in agreement with Breman and Cisse (1977) findings as shown in Fig. 2.5 and findings by Breman *et al*. (1979/80). However, Hiernaux (1996) emphasized that species like *Zornia* were not restricted to areas under high grazing pressure and invaded large areas of sandy rangelands in the southern Sahel after the 1983-84 drought. Thus, changes in botanical composition in response to drought are sometimes similar to those in response to grazing pressure.

Rainfall and soil characteristics also determine vegetation dynamics and that is why Sahelian pastures are highly heterogeneous. In a study by Breman *et al*. (1979/80), the total biomass and relative importance of dominant species at the end of the rainy season varied from 0.6 to 2.5 t/ha in 4 successive years, while in each year, a different species dominated the biomass. It was noted that the study site was at the 400 mm isohyet, on a slightly undulated sandy area and was lightly grazed. This variation in botanical composition could be explained by the effect of rainfall and its variability.

Pasture management and Sahelian pastures

To persist by reseeding or/and re-growth from existing plants, forage grasses and legumes must be given sufficient time between defoliations, this is because the time between defoliation helps the plant to produce and store enough energy for re-growth (Smith, 1962). Plant response to defoliation depends on plant species, the extent of removal of leaf area and growing points, and the amount of carbohydrate available for re-growth. Therefore, good management (such as rotational grazing) of these grasses should allow sufficient time between defoliations to restore carbohydrate reserves or leave enough leaf area for carbohydrate production. Because plants differ in their morphological and physiological responses to different management strategies, in a mixed species pasture it is possible to see the dominance of one or two species at any given time.

In a grazing situation, livestock preference for one species or plant part over another depends on relative palatability, acceptability, and overall availability of pasture species or parts. Any plant that can adapt to defoliation in a pasture setting needs meristematic tissue close to the ground, out of danger of removal by livestock (Harris, 1978), because after defoliation leaves re-grow from meristematic tissue at the base of each leaf and new leaves arise from auxiliary buds also located near the base of leaves (Smith, 1973). These tissues must be close to the soil surface to escape damage during defoliation in order to allow subsequent re-growth. Plants with upright growth patterns are more sensitive to defoliation, and recover more slowly than plants with a horizontal growth pattern (Butler *et al*., 1959). Livestock grazing can influence grass/legume composition of a pasture (Schwinning and Parsons, 1996a), because livestock will selectively graze more palatable legumes in preference to less palatable grasses. This selectivity can lead to grass domination in pastures, especially when continuously grazed (Watkin and Clements, 1974). Thornley *et al*. (1995) state that persistence of unfertilized mixtures of *Lolium perenne* (rye grass) and *Trifolium repens* (white clover), is not achievable, except when grazing eliminates the dominance of white clover. If a legume is highly competitive with grasses, the grass can often be maintained in the mixture only by the presence of grazing animals (Schwinning and Parsons, 1996a). Depending on the severity of defoliation, grazing can reduce root mass and depth. Root morphology is an important factor in successful competition for water and nutrients in a pasture (Evans, 1977). A more developed and deeper root system generally gives one pasture species an advantage over another (Davidson, 1978). In general, grasses have longer, thinner, more finely branched roots, and more root hairs, than legumes (Evans, 1978). These differences in root structure and root depth could give grasses a competitive advantage over legumes in nutrient and water uptake (Haynes, 1980), and could partially explain why grasses are better able to absorb limiting nutrients. However, legumes have deep taproots that are able to reach water and nutrients at deeper depths.

In the Sahel, some of the common adaptation techniques to drought stress include: leaves falling or the whole above ground growth falling, morphological and anatomical modifications such as narrower leaves, rolled or folded leaves, reduction in the development cycle, and root system development. Generally, lateral or horizontal root systems in shallow depth soils utilize water from rainfall that humidifies the surface, and vertical roots utilize deeper horizons; an example is *Acacia* (Breman *et al*., 1979/80). Growth and nutrient uptake of annual rangeland plants in response to defoliation were studied at 13 sandy rangeland sites located across the Sahelian zone of Mali. Results show that above-ground growth response to repeated clipping treatments was more strongly affected by growing condition, such as rainfall, than by the frequency of clipping (Hiernaux and Turner, 1996). Clipping response was found to be quite variable. Hiernaux and Turner (1996) concluded that the effect of clipping every 15 or 30 days on biomass accumulation varied significantly and was affected by growing conditions and plant phenology. Hiernaux (1996) found that repeated clippings during the growing season prevented annual plants from setting seeds. The Sahelian rangelands are dominated by annual plants, and biomass production therefore depends on plant density, which is ultimately dependant on the number of seeds germinating per unit area. Thus, repeated clippings could lead to a reduction in plant density. Repeated defoliation could also lead to a progressive reduction in soil fertility due to increased nutrient uptake by harvested plants (Hiernaux, 1996). Although this effect has not been measured, the reduction in production following repeated clipping, in contrast to the increase in production observed when fertilizer was applied (Hiernaux *et al*., 1992) suggested that effect.

The relative importance of climatic variation and grazing effects on pasture productivity has been an ongoing debate. Grazing during the growing season may either increase or reduce productivity, depending on the seasonality and intensity of the activity (Hiernaux et al, 1992). Environmental variables such as soil texture and distribution of rainfall also affect productivity, thus the interaction of these various factors create a complex system. Although the Sahelian vegetation appears very resilient to environmental (abiotic) and biological (biotic) stresses. The increase in sedentary agro-pastoralism, in which persistent grazing during the rainy season on a restricted area of rangeland is common, can lead to regional-scale land degradation (Haywood, 1980; Breman and De Ridder, 1991). Traditional methods of *opportunistic* grazing are decreasing and sedentary agro-pastoralism is replacing the traditional movement of herd and people (transhumance and/or nomadism). More research is needed in the management of Sahelian annual rangelands under a sedentary grazing system.

It is very well established that rotational stocking is among 'best management practices' in intensive or extensive production systems in the US and other developed countries. However it can be very difficult to implement in the Sahelian zone of West Africa because fencing large areas will interfere with traditional nomadic/transhumant movements and because it would not be economically feasible. Tethering is a useful grazing method where land is in short supply, or where it is not possible to build fences to subdivide pastures into paddocks.

Cantillon *et al*. (1986) measured intake levels, bite rate, bite size and how these parameters are influenced by pasture composition, length of grazing time and time of day, in a tethered system. There were no significant differences in intake levels across the different plant species and replications; however variation occurred in the manner in which the forage was grazed. Bite rate and bite size appeared to be inversely related. There were no reports of plant evaluation in this study. The authors concluded that tethered grazing is a fast, economical approach through which unanswered questions concerning nutritional contribution of forages and the interaction of horse and forage can be examined. There is very little scientific exploration on the effect of tethered grazing on plant diversity, forage quality, and soil fertility.

The potential role of Cassia tora

Identification and distribution

Cassia (Senna) tora L., *foetid cassia*, *C. (S.) obtusifolia* L., sicklepod, coffee weed, etc., are very closely related annual weedy shrubs belonging to the family *Caesalpiniaceae* in the order Leguminosae (Cock and Evans, 1984). *Cassia* is a weed of

26 crops in 67 countries and is more prevalent in *Glycine max* (soybeans), *Arachis hypogaea* (peanuts), pastures, *Gossypium hirsutum* (cotton) and *Saccharum officinarum* (sugarcane) than other crops. *Cassia obtusifolia* commonly known, as coffeeweed, sicklepod, or coffee-pod, is the most prevalent species of *Cassia*, can reach heights of 1.8 to 2.1 m, and produces sickle-shaped seedpods. The teardrop-shaped leaves grow in clusters of 4 to 6 leaflets. It is often confused with *C. tora*. In fact, it is difficult to distinguish between the two (Brenan, 1958). Some investigators claim to have seen plants intermediate between the two species. Bhandari (1978) treated *C. tora* as the synonym of *C. obtusifolia.*

Others distinguished the two on the basis of epidermal structure and seed analysis (Mall, 1957; Pandey, 1970; and Mathur, 1985). Randell (1995) discussed the possibility that *C. tora* evolved in Asia from *C. obtusifolia*. *Cassia obtusifolia* is well documented as a weed of peanuts and soybeans in the southern USA, and is widespread throughout the tropical world. *C. tora* is becoming increasingly prominent as a pasture weed in the Southwestern Pacific, Asia, and Africa. De Wit (1955) characterized *C. tora* as a weed species throughout the tropics, probably of South American origin. Singh *et al*. (1970) characterized it as a minor weed of various crops but of greatest importance as a pasture weed and suggested that it has become established in response to overgrazing.

Biological significance of Cassia tora

Most plant species have evolved with predators that eat them. This raises the question of what happens if someone takes a plant and moves it to a place where its predator does not exist. To keep its population under control, the plant needs its predator. When a plant is reproducing without control and pushing out native plant species, it becomes a weed or an invasive exotic plant. Ehrenfeld (2003) sees the invasive species not as a threat to biodiversity and ecosystem stability, but rather as a potential threat to natural nutrient cycling processes in the soil. Ehrenfeld (2003) reviewed data on invasive species and soil nutrient cycling and suggested that invasive plant species frequently increase N availability, alter N fixation, and produce litter with higher decomposition rates than coexisting native species. Most of Ehrenfeld (2003) data was based on observational studies, and there is very little information on the time since invasion, the causes of invasion, and plant densities.

Davis (2003) states that extinction often results from the combined effects of multiple processes, such as over-harvesting and habitat loss. Therefore competition from introduced species might not be the primary cause of native species extinction, but can be a contributing factor. Davis (2003) describes the phenomenon of *dispersal*, first evoked by Hubbell (2001) in his theory of "ecological drift", as a positive factor of global biodiversity. Competition from introduced species is not likely to be a common cause of extinctions of long-term resident species according to Davis (2003). Chandrasekaran and Swamy (2002) studied the influence of an herbaceous weed community on natural secondary forest and man-modified ecosystems. Man-modified ecosystems showed significantly greater weed density than the natural ecosystem; the researchers attribute this difference to a higher incidence of exotic weed species in man-modified ecosystems due to a higher degree of disturbance and open environment. In addition, the sites invaded by the exotic weeds showed higher herbaceous litter production. Uhl and Jordan (1984) attribute the production of successional forests to the release of nutrients from the decomposition of herbaceous litter. These studies suggest that exotic plant invasions influence the ecosystem structure, species composition, and aboveground biomass.

Cassia tora, if managed, could improve pasture productivity by providing more litter and increasing organic matter in the soil as well as recycling essential nutrients. It could also provide a source of feed during the dry season if used as silage.

Cassia as forage

Although *Cassia tora* is considered a poisonous plant, the toxic coumpound in *Cassia* has not been clearly defined. The seeds appear to exert their toxicity upon the skeletal muscles, kidney, and liver. The leaves and stem also contain toxin, whether green or dry. The plant can poison animals if they consume it in the field, in green chop, in hay or in grain containing the seed. Perkins and Payne (1985) suggest that anthraquinones found in the leaves are the toxic compounds of this plant. Others report that the seeds of the plant contain emodin, other anthraquinones and xanthones (Manjunath and Subbajois, 1930; Gupta and Sharma, 1965; Rangaswami, 1963). Tiwari and Behari (1972) have found anthraquinones in the roots of *C. tora*. Pal *et al*. (1977) have also found emodin from the leaves of *C. tora*. Toxicity has been observed in cattle and broilers, and other animals are also susceptible to the effects of this plant. In cattle, diarrhea is usually the observable first symptom of poisoning. Later, the animals go off feed, appear lethargic, and tremors appear in the hind legs, indicating muscle degeneration. As the symptoms progress, the urine darkens to the color of coffee, and the animal becomes recumbent and is unable to rise. Death often occurs within 12 hours after the animal goes down.

In their study, Sood *et al*. (1990) used *C. tora* seeds as a potential poultry feed. The seeds were treated with sodium hydroxide followed by rectified spirit (alcohol) to lower the toxicity. Sood *et al*. (1990) concluded that *Cassia tora* could be fed up to the 10% level without affecting animal health or performance. Other researchers suggested the presence of tannins and saponins in the seed of *C. tora*. Lower feed intake, poor growth response coupled with enlarged and fatty livers, reduced spleens and haemolysed erythrocytes (destruction of red blood cells) suggested the presence of these toxins in *Cassia* seeds (Katoch *et al*. 1978, Katoch and Bhowmik, 1983). Chand and Katoch (1983) reported that 0.1 N sodium hydroxide treatments to *C. tora* meal resulted in 77.27% tannin extraction and 25% saponin extraction, and treatment with rectified spirit eliminated these coumpounds by 35.61% and 58.33%, respectively. However, more research needs to be done in order to characterize the exact cause of *Cassia* toxicity, particularly because, as some herders in Madiama pointed out, the small ruminants eat *C. tora* in the pasture fresh or dry if nothing better is available.

Cassia tora, known as Chakwar in India and Jue-ming-zi (seeds of the legume) in China, has many virtues, attributed to the anthraquinones present within the plan, and is used as a medicinal plant in these countries as well as in Africa. The seed of *C. tora* has physiological functions as an antiseptic, diuretic, diarrheal, antioxidant, and antimutagen (Wu *et al*., 2001). The water extract of *C. tora* has been used as a health beverage in China. In India, *C. tora* is also utilized to feed livestock, because Chakwar (*C. tora*) seeds have been found to be very rich in protein. Patel *et a*l. (1971) evaluated *Cassia* seeds in partial replacement of concentrate mixture from the ration of milking cows. *Cassia* seeds were boiled in water, dried and ground. The results showed that 15% boiled *Cassia* seeds could be included in the ration of cows without any adverse effect, and a net profit per animal and per year was observed when using this ration.

Singh *et al.* (2001) conducted an experiment on broilers looking at the impact of *C. tora* seed on growth and meat production. The results indicated that *C. tora* seed could be safely incorporated up to the 10% level in broiler mash for maximum return on least expenditure. This study confirmed results found previously by Pandit *et al.* (1979). These reports indicate that *Cassia* seeds could be incorporated in animal feed, but it would be even better if the entire plant could be utilized as a source of feed.

Previous studies by Gupta *et al*. (1970), as cited in Ranjhan *et al*. (1971) have shown that a neglected summer legume (*C. tora*) that is not accepted in the green stage, when conserved as silage with or without molasses was readily accepted by livestock and was quite nutritious. Ranjhan *et al*. (1971) reviewed the chemical composition and nutritive value of *C. tora* fed as hay and compared it to the *C. tora* fed as a green plant and/or as silage. The green plant was collected at flowering stage, air dried for a day, and stored in the shed for a day until the dry matter content of the fodder reached approximately 75%. The hay was evaluated after a month and fed to adult sheep. Palatability was determined using four yearling rams and four three-year old male buffalo calves. Gupta *et al*. (1970) as cited in Ranjhan *et al*. (1971) observed that the fodder was palatable and could be compared to the dry matter consumption observed on feeding *C. tora* silage. The chemical composition and nutritive value of *C. tora* hay was found to contain 12.70, 26.80, 1.76, 46.95, 2.41, and 0.64 of crude protein, crude fiber, ether extract, nitrogen free extract, ash, calcium and phosphorous, respectively. The digestibility coefficients for organic nutrients in *C. tora* hay were significantly more than the silage Gupta *et al*. (1970) as cited by Ranjhan *et al*. (1971) reported earlier. The data for the chemical composition and digestibility of *C. tora* hay as compared to silage are given in chapter IV (see Table 4.1 & 4.2).

The silage concept is more prevalent in temperate regions, with their distinct seasons, than in the tropics. Nevertheless, silage production in the tropics has become more relevant to fulfill the forage needs of smallholder farmers (FAO, 2000). Silage making is less dependent on weather conditions than haymaking. More research needs to be done to determine the potential of *C. tora* conservation as silage and to evaluate the nutrition and toxicity of *Cassia* silage.

Soil fertility

Africa south of the Sahara is the only remaining region of the world where per capita food production has remained stagnant or declined over the past 40 years. Approximately 180 million Africans do not have access to sufficient food to lead healthy and productive lives, making them more susceptible to the ravages of malaria, HIV-AIDS, and tuberculosis (Sanchez, 2002). Absolute poverty is coupled with an increasingly damaged natural resource base. Low soil fertility, particularly N and P deficiencies, is one of the major biophysical constraints affecting African agriculture (FAO, 1971; DeWit, 1981; Penning de Vries & Djiteye, 1982; Mokwunye et al., 1996). Until very recently, the focus has been primary on other biophysical limitations such as soil erosion, drought, and the need for improved crop germplasm (Sanchez et al., 1997). Sanchez et al. (1997) explains that no matter how effectively other conditions are improved, per capita food production in Africa will continue to decrease unless soil fertility depletion is effectively addressed. They describe the magnitude of nutrient depletion in sub-Sahara Africa as enormous: an average of 660 kg N ha^{-1}, 75 kg P ha^{-1}, and 450 kg K ha^{-1} has been lost during the last 30 yrs from about 200 million ha of cultivated land in 37 countries. This is equivalent to 1.4 t urea ha^{-1}, 375 kg triple superphosphate (TSP) ha^{-1}or 0.9 t PR of average composition ha^{-1}, and 896 kg KCl ha^{-1} during the last three decades. These figures represent the balance between nutrient inputs (fertilizer, manure, atmospheric deposition, biological N_2 fixation, and sedimentation), and nutrient outputs (harvested products, crop residue removals, leaching, gaseous losses, surface runoff, and erosion). According to FAO (1995), sub-Sahara Africa is losing 4.4 million t N, 0.5 million t P, and 3 million t K every year from its cultivated land, these rates being several times higher than its annual fertilizer consumption. The vast majority of farmers lack the means to buy fertilizers. Consequently, farming has become soil mining, which is defined as the removal (removed by harvesting crops, wind erosion, etc.) each year of more nutrients than are being added (Van der Pol, 1992).

Low P availability in tropical acid soils often rises from fixation of P by Al and Fe in soil. Generally, Al and Fe-phosphates are relatively unavailable to plants; however, some legumes are able to utilize unavailable forms of P (Ae et al., 1990). Identifying such legumes would be useful for maintaining productivity without further addition of fertilizer P and N (Sanchez and Salinas, 1981). Ae et al. (1990) investigated the ability of *Cajanus cajan* (L.) Millsp. (pigeon pea) to extract soil P forms considered normally unavailable to other crop plants. The investigators found that pigeon pea exhibited much greater dry matter production and P uptake on an Alfisol without any fertilizer P than on a Vertisol. They concluded that the better growth of pigeon pea on the Alfisol was related to its ability to utilize Fe-P, which was the dominant form of P in the Alfisol. It was also suggested in this study that root distribution and vesicular arbuscular mycorrhizal (VAM) were not the reason for the differences between pigeon pea and the other crops tested and that more research is needed to look at root exudates and the ability of some compounds to chelate Fe^3+ from $FePO_4$. Pisidic acid (p-hydroxybenzyl tartaric acid) was one of the organic acids analyzed in this study. Pigeon pea and *Cicer arietinum* L. (chickpea) have been identified to usually grow well in low soil P environments. In a study by Itoh (1987), pigeon pea and chickpea were found to be able to take up more P at lower concentrations of P as compared to *Glycine max* (soybean) and *Zea mays* (maize) that responded better to higher P applications.

In a more recent study by Zoysa et al. (1999) in the tropics, P utilization efficiency and depletion of phosphate fractions in the rhizosphere of three *Camellia thea* L. (tea) clones were observed. All three tea clones induced acidification of the rhizosphere and researchers attributed higher P uptake efficiency of two clones to their higher root acidification, root exudation of organic compounds, and/or mycorrhizal association. Ascencio (1996) studied the effects of P deficiency on the physiology of two tropical leguminous species. The author suggested that enzyme activity, total leaf area, and relative growth rate (during exponential growth phase) were appropriate physiological indicators for the differentiation of *Desmodium* plants grown under P deficiency or sufficiency. The results indicated that the activity of acid phosphatase secreted by the roots increased under P deficiency in both species.

Sanchez and Salinas (1981) examined the effectiveness of various phosphate rocks as compared to that of triple superphosphate, using *Panicum maximum* as the test crop on an Oxisol from the Llanos Orientakes of Colombia. Three phosphate rocks were tested; a high-reactivity phosphate rock from North Carolina, a medium-reactivity rock from Florida, and a low-reactivity rock from Brazil, Colombia, and Venezuela. Phosphate rocks performed nearly as well as the triple superphosphate and in some instances outperformed the triple superphosphate in the long run. Mali's major mineral resources include rock phosphate. Tilemsi phosphate rock (Tilemsi PR) in Mali has been tested as direct application phosphate fertilizer in various experiments (Diamond et al., 1989; Chien and Menon, 1995). The results showed that the relative agronomic effectiveness (RAE) of directly applied ground Tilemsi PR was close to that of triple superphosphate (TSP). Bationo et al. (1997) findings are in agreements with Diamond et al. (1989) and Chien and Menon (1995), showing that direct applications of Tilemsi PR resulted in yields comparable to those of recommended imported fertilizers for *Gossypium* (cotton) or cereal crops.

Hoffland (1991) studied the uptake of P from sparingly soluble rock phosphate by *Brassica napus* (rape). It was found that phosphate-deficient rape plants are able to mobilize rock phosphate by exuding organic acids, malic and citric acids in particular, causing acidification of the rhizosphere. Hoveland et al. (1976) have found that *Cassia occidentalis* L. and *Cassia obtusifolia* L. (sicklepod) among other tropical legumes were the most tolerant of low available soil P. Mappaona and Yoshida (1995) studied the growth and nitrogen fixation of three leguminous plants under various forms of P applications; *C. tora* was identified as a non-nodulated legume and was found to have an intermediate response to P fertilization in this study. *Cassia* is found throughout the tropics and grows abundantly in our experimental sites in Mali under very low soil P and degraded soil conditions. Quantitative information on *Cassia*'s ability to cope with low P environments is unavailable. Experiments are needed to characterize the growth mechanisms of *C. tora* under various soil P levels and to examine which sources of applied P *C. tora* utilizes most effectively.

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List of figures

Fig. 2.1 Map of the Sahelian zone in West Africa (Ridder *et al*., 1982).

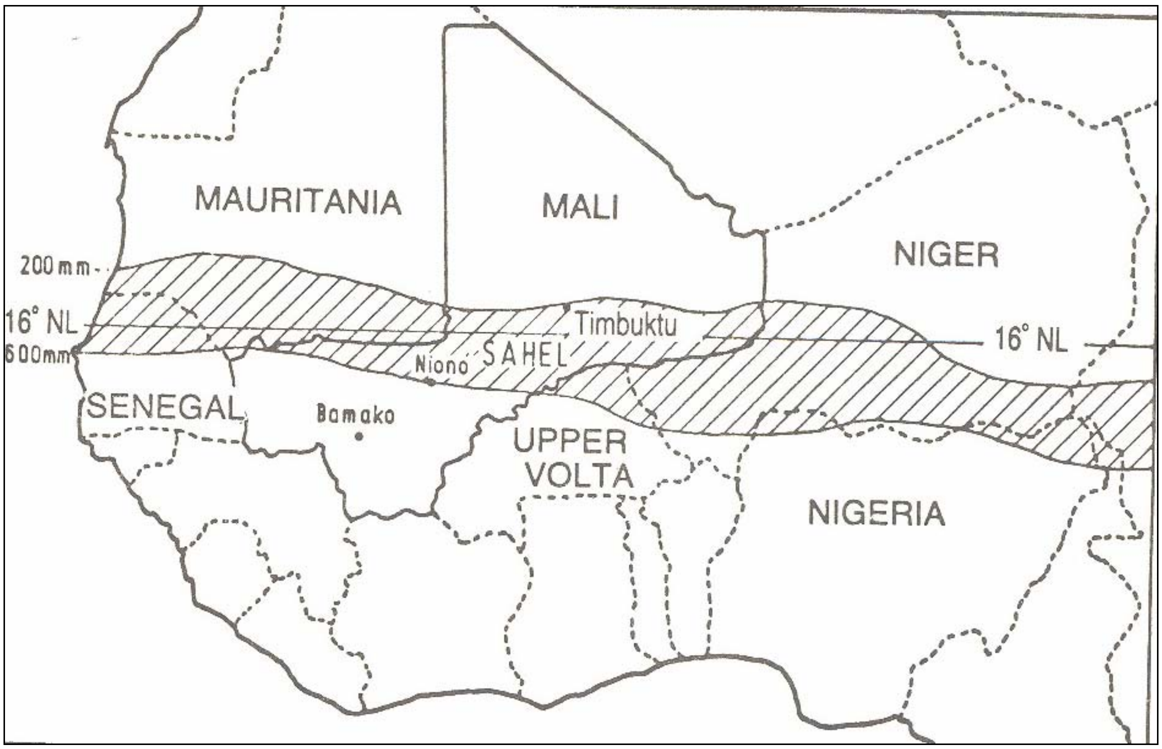


Fig. 2.2 Annual rainfall of the West African Sahel (Ridder *et al*., 1982).

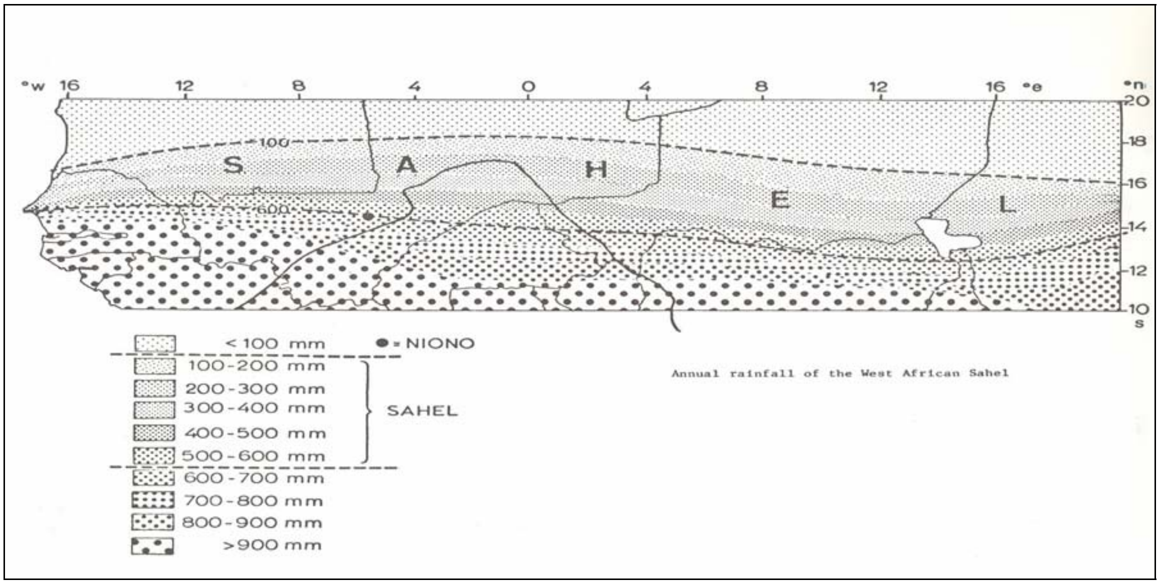


Fig. 2.3 Potential evapotranspiration for two Sahelian zones (Cocheme and Franquin, 1967 as cited by Ridder *et al*., 1982).

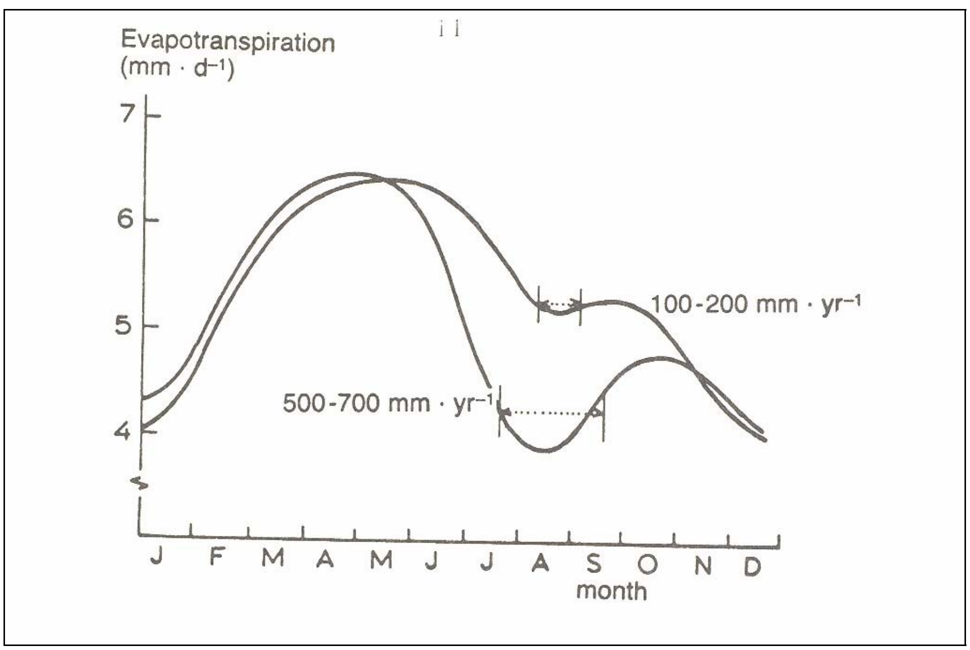
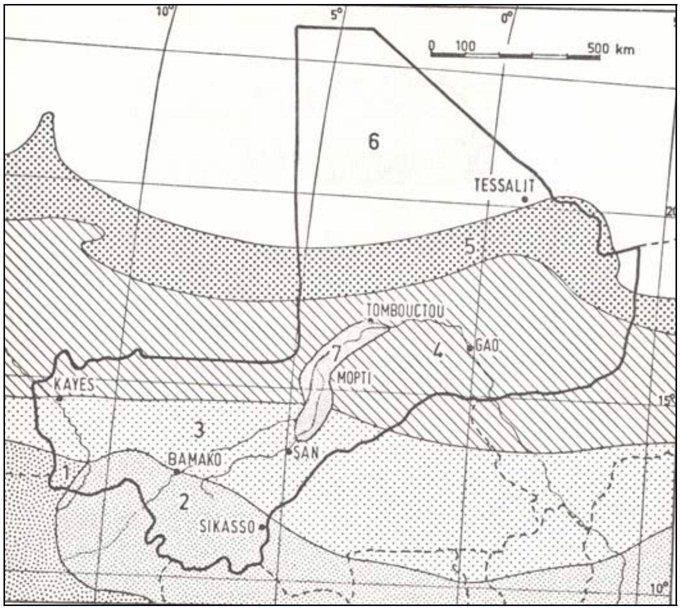
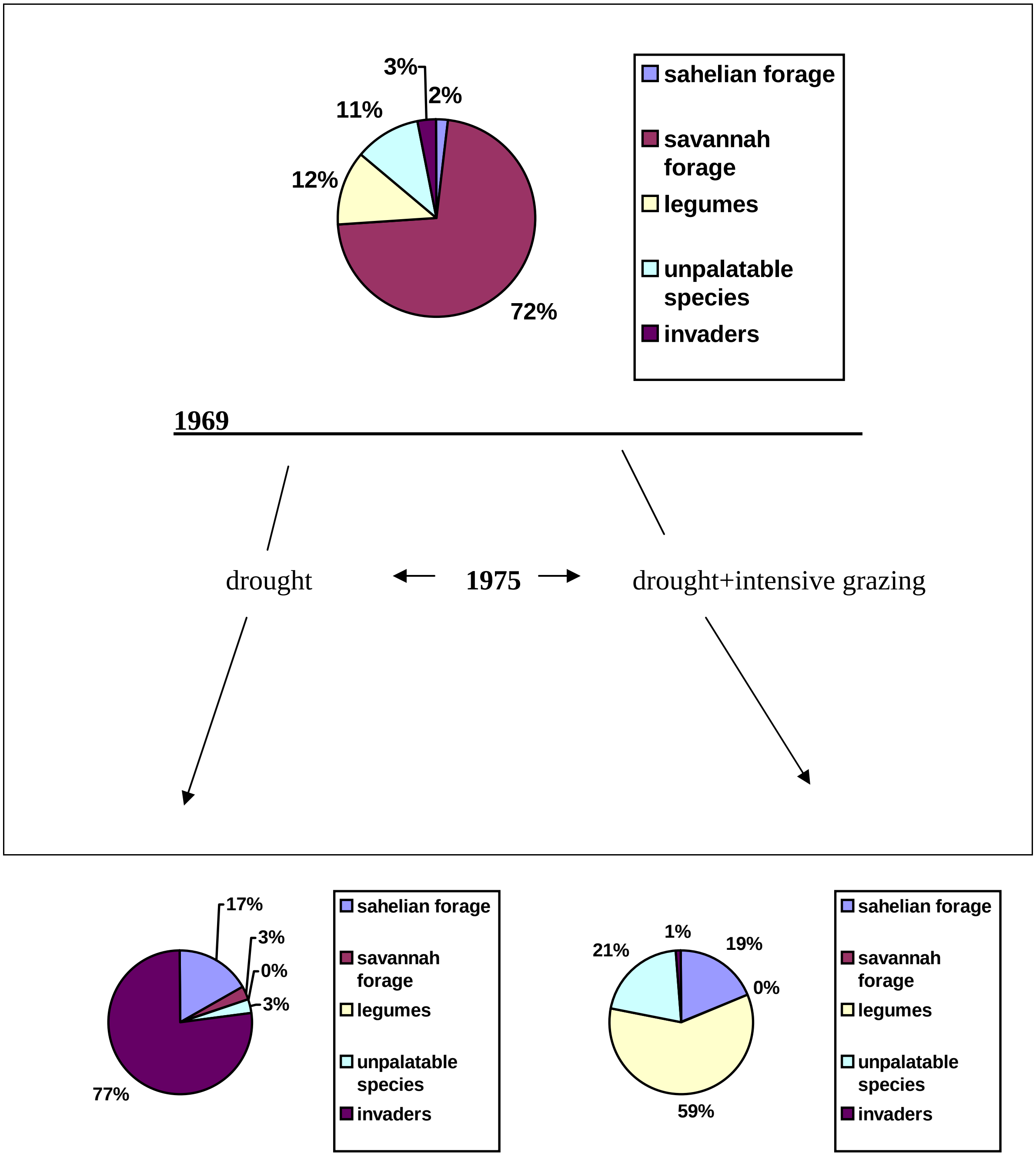


Fig. 2.4 Vegetation zones of Mali (according to "Map of African Vegetation South of the Tropic cancer" UNESCO, 1959; Diarra, 1971).



1. Clear forest
2. Wooded savanna
3. Herbaceous savanna
4. Wooded steppes with an abundance of Acacia (Sahel)
5. Sub-desert steppes
6. Desert (Sahara region)
7. Flood zone

Fig. 2.5 The influence of drought and grazing on the herb layer of a pasture in the transition zone from savanna to Sahel (Breman and Cisse, 1977).



CHAPTER III

The influence of tethered sheep grazing on botanical composition, forage production and animal performance

Abstract

Desertification and drought have reduced usable land at a rate of 80,000 hectares per year in the Sahel. In the Mopti region of Mali, West Africa (which includes Madiama Commune), the lack of pasture and forage resources for livestock has been a growing problem. Pastoral resources in the Madiama commune include: bourgoutieres (wetlands), dry land pastures sustaining mostly annual herbaceous species, and crop residues. A grazing experiment was initiated to determine the influence of sheep grazing tethered at two different residual heights on botanical composition, forage biomass production and animal performance. Young sheep weighing approximately 18-24 kg were tethered for a certain period of time depending on residual canopy height. Two treatments 3 or 6 cm residual height were each replicated 4 times. Animals were rotated based on canopy height and a total of 8 paddocks completed the entire rotation for each tethered animal. Forage biomass production, plant diversity and animal performance were assessed. The end of season evaluation showed that close grazing caused a redistribution and replacement of the more desirable grasses by more weedy types of plants. Accumulated forage yield increased with time while forage quality declined. Seasonal weight gain of animals showed little difference between treatments. Quality of the forage rather than quantity may have contributed to the low weight gain of the grazing animals.

Introduction

The lack of pasture and forage resources has been a growing problem in the Sahel region of sub-Sahara Africa. Population growth, extensive row cropping, increasing herd size, high levels of exploitation of woody resources, and climatic fluctuations have all contributed to serious losses of plant biodiversity within this region. In addition, utilization of greatly reduced pastureland resources has become a major source of conflict between farmers and herders.

The unimodal annual rainfall pattern limits grazing potential in Madiama, with respect to plant community composition, yield and quality. Perennial species, herbaceous as well as woody, have become scarce over the years. The less dependable annual grasses and other low forage quality species severely limit potential animal production. As perennial forages in these pastures have become nearly non-existent, annual grasses and some legumes have become the dominant species in the Madiama Commune. Seasonal movement of animals (transhumant practices) is also increasingly limited, resulting in overpopulation of animals and overgrazing. The existing low level of plant succession under the current management system has resulted in a severe botanical shift from dominantly perennial grasses to annual grasses and from a grass-legume mixture to an almost pure grass sward.

To persist by reseeding and/or re-growth from existing plants, forage grasses and legumes must be given sufficient time between defoliations. Increased time between defoliation helps the plant to produce and store enough energy for re-growth (Smith, 1962) and reseeding. Plant response to defoliation depends on plant species, the extent of removal of leaf area and growing points, and the amount of carbohydrate available for re-growth. Therefore, good forage management (such as rotational grazing) should allow sufficient time between defoliations to restore carbohydrate reserves and leave leaf area for carbohydrate production. Because plants differ in their morphological and physiological responses to different management strategies, in a mixed species pasture it is possible to see the dominance of one or two species at any given time.

In the Sahel, some of the common adaptation techniques to drought stress include: abscission of the leaves or senescence of the whole plant; morphological and anatomical modifications including narrower leaves, rolled or folded leaves, reduction in the development cycle, and changes in root system development. For example, *Acacia* has a horizontal root system in shallow depth soils to utilize water from rainfall, and vertical roots to utilize deeper horizons (Breman *et al*., 1979/80). Growth and nutrient uptake of annual rangeland plants in response to defoliation were studied at 13 sandy rangelands sites located across the Sahelian zone of Mali (Hiernaux and Turner, 1996). Results showed that above-ground growth response to repeated clipping was more strongly affected by growing condition, such as rainfall, than by the frequency of clipping (Hiernaux and Turner, 1996). They concluded that the effect of clipping every 15 or 30 days on biomass accumulation varied significantly and was affected by growing conditions and plant phenology. Hiernaux (1996) also found that repeated clippings consistently increased nitrogen and phosphorus uptake across a wide range of growing conditions; however, repeating clipping during the growing season prevented annual plants from setting seeds.

The Sahelian rangelands are dominated by annual plants and therefore depend on on the number of seeds germinating per unit area to maintain plant density. Repeated clipping or grazing could lead to a reduction in plant density. Repeated defoliation could also lead to a progressive reduction in soil fertility due to the increased nutrient uptake and removal by plants (Hiernaux, 1996). Hiernaux *et al*. (1992) suggested a reduction in production following repeated clipping, in contrast to the increase in production observed when fertilizer was applied.

The relative importance of climatic variation and grazing effects on pasture productivity has been an ongoing debate. Grazing during the growing season may either increase or reduce productivity, depending on the seasonality and intensity of the activity (Hiernaux *et al*., 1992). Environmental variables such as soil texture and distribution of rainfall also affect productivity, thus the interaction of these various factors create a complex natural system. Although the Sahelian vegetation appears very resilient to environmental (abiotic) and biological (biotic) stresses. The increase in sedentary agro-pastoralism, in which persistent grazing during the rainy season on a restricted area of rangeland is common, can lead to regional-scale land degradation (Haywood, 1980). Traditional methods of *opportunistic* grazing are decreasing and sedentary agro-pastoralism is replacing traditional movement of herd and people (transhumance and/or nomadism). More research is needed in the management of Sahelian annual rangelands under a sedentary grazing system.

It is very well established that rotational stocking is among the 'best management practices' for intensive or extensive production systems in the US and other developed countries. However rotational grazing is very difficult to implement in the Sahelian zone of West Africa because fencing large areas interferes with traditional nomadic/transhumant movements and because it is rarely economically feasible. Tethering is a useful grazing method where land is in short supply, or where it is not possible to build fences to subdivide pastures into paddocks. Dougherty *et al*. (1987) recommends the tethering technique for studies of grazing behavior.

Cantillon et al. (1986) measured intake levels, bite rate, bite size and how these parameters are influenced by pasture composition, length of grazing time and time of day, in a tethered system using horses. There were no significant differences in intake levels across the different plant species and replications; however variation occurred in the manner in which the forage was grazed. Bite rate and bite size appeared to be inversely related. There were no reports of plant evaluation in this study. The authors concluded that tethered grazing is a fast, economical approach through which unanswered questions concerning nutritional contribution of forages and the interaction of horse and forage can be examined. There is very little scientific exploration on the effect of tethered grazing on plant diversity, forage quality, and soil fertility.

The importance of managing for natural succession in order to restore pastureland resources and determine indicators for improving pasture management practices was the purpose of this experiment. The specific objectives of this experiment were: (1) to determine the influence of the tethered grazing method on plant diversity in the Sahelian pastures of Mali; and (2) to evaluate animal performance in terms of weight gains under tethered grazing.

Materials and Methods

In 2003 a study was conducted at two villages (Siragourou and Nérékoro) within Madiama Commune. At both locations, an area was fenced to keep animals and people out of the experimental plots. At both the Siragourou and Nérékoro villages young sheep weighing 18-24 kg and 18-21 kg were used. Since the purpose of the experiment was to determine indicators for optimal pasture management, the experiment involved two treatments: 3 cm vs. 6 cm forage residual heights, each replicated four times (Fig 3.1). Animals were weighed and tagged according treatments and treated for internal parasites and randomized according to weight and treatment. Each animal within its grazing area represented an experimental unit; therefore a total of eight animals per site were used. Residual plant height was determined based on measurements taken prior to the initiation of the experiment. The initial height of the forages at each site varied from 5 to 20 cm and 8 to 14 cm for the Siragourou and Nérékoro locations, respectively (Table 3.1). Each animal was tethered separately to its own peg using a 6-meter length of rope that allowed the animal to consume all forage within its range (113m^2 area) for the period of time determined by available forage and canopy residual height (Fig. 3.2). Once each animal grazed its area to the 3 or 6 cm residual plant height, it was then rotated to the next peg (8 pegs experimental unit^{-1} = 1 complete grazing cycle) (Fig. 3.1). Water was provided to the animals daily at the grazing location. At night, the animals were kept in a kraal. And no additional feed was provided.

Although the plan was to weigh the animals following each grazing cycle, due to exceptionally abundant forage production during the 2003 growing season, no more than seven pegs (paddocks) were utilized during the season. Therefore, the animals were weighed only at the beginning and the end of the grazing season, instead of at the end of each grazing cycle. At both locations, guards were trained to watch animals, provide water, and take the animals home at night. Animals remained on pasture for a total of 93 days.

The botanical composition of pastures was determined by a non-destructive visual evaluation method using the Double DAFOR Scale (Brodie, 1985; Abaye *et al.*, 1997), where D=dominant, A=abundant, F=frequent, O=occasional, and R=rare are used to evaluate the relative abundance of species. Brodie (1985) describes a species as dominant if it covers most or all of the area. A ranking of abundant is given to species that cover approximately one half to three-quarters of an area. Frequent ranking refers to species well scattered throughout a site but covering less than half the area. A species ranked as occasional occurs a few times, and a rare species is one that is present only once or twice. Brodie (1985) suggests that problems with this method include under-assessment of smaller species, over-assessment of conspicuous species and miss identification of species. Initially (August) the entire pasture was visually evaluated for both ground cover and species diversity. At the end of the grazing season (November) the grazed area (all paddocks and all treatments) and the ungrazed area (outside of the 6 m circled area grazed by animals) were evaluated for ground cover and botanical composition using the DAFOR Scale.

In addition, prior to moving an animal to a new paddock, a 0.25 m^2 area was harvested (clipped to 5cm residual height) from the ungrazed corners to measure the potential forage biomass production for each animal. Sub-samples from the biomass sample were obtained, dried in a forced-air oven at 60^oC, ground (1-mm screen) in a stainless steel Wiley Mill (Thomas-Willey Mill, Model ED-5, Arthur H. Thomas Co., Philadelphia, PA), and analyzed for ADF (Van Soest, 1963). Total N was determined colorimetrically (McKenzie and Wallace, 1954) with a Technicon Autoanalyzer (Technicon Industrial Systems, Tarrytown, NY; 1976).

Soil samples to a depth of 10 cm were obtained prior to the start of grazing by taking six to ten soil cores from each treatment replication (areas with tethered grazing and ungrazed areas) Samples were analyzed for N, P, K, and pH in the IER Soils Laboratory at the CRRA/Sotuba.

Statistical analysis

A randomized complete block design (RCBD) was used to perform the analysis. Analysis of variance (ANOVA) procedures were performed on all data to test the treatment effects on all ‘even’ sets of data using the GLM procedure of SAS (SAS Inst., 2001). The treatment means were compared using least significant difference (LSD) at P = 0.05. The statistical analysis Systems Mixed Procedure (Littell et al., 1006; Bowley, 1999) was used to analyze parameters on the uneven sets of data. Three separate analyses were performed for the initial evaluation (ground cover) of ungrazed areas, the grazed areas with treatment (3 or 6 cm) effect, and final evaluation of ungrazed areas. Percent ground cover for the third analysis was tested for Y = % ground cover ungrazed - % ground cover grazed. The analyses on measured parameters from the ungrazed areas (initial and final) included potential forage biomass and forage quality parameters as affected by harvest date.

Result and discussion

Weather data for the Madiama Commune

The total amount of rainfall received during the 2003 growing season exceeded the 1999 to 2002 average annual rainfall. The total annual rainfall for 1999, 2000, 2001, 2002 and 2003 was 602.1 mm, 507.4 mm, 678.1 mm, 374.5 mm, and 1130 mm, respectively. The monthly rainfalls for 2003 exceeded all but the May and June rainfalls for 1999-2003, (Fig. 3.3). The rainfall for July, August, September and October of 2003 was higher than the previous four years. Rainfall usually begins declining in September and stops completely by the end of October. In 2003, 31.5 mm rain was recorded for November.

Forage ground cover, species diversity, biomass, and quality assessments

Nérékoro location

The effect of treatments on ground cover is illustrated in Fig. 3.4. Residual grazing height resulted in no difference in percent ground cover (Fig. 3.4). Although not significant, the end of the grazing season ground cover trended lower where animals grazed compared with areas not grazed throughout the grazing season. The 80% plus ground cover observed in 2003 (regardless of treatment) was reflective of increased forage production caused by the above average precipitation. Initially, in the grazing area, the dominant grass species were *Dactyloctenium aegyptium* (Da), *Panicum laetum* (Pl) and *Bracaria* sp. (Bsp), which are all highly palatable to livestock. However, the relative abundance of these species was less frequent in parts of the same grazing areas (Table 3.2). Among the few legumes found at this site, *Cassia tora* (Ct) (sickle pod) was predominant. This annual legume, widely known in the United States as a noxious weed mostly found in soybean fields, is extremely aggressive. Most grasses do not compete well with *Cassia tora* (Ct) because of its aggressive and invasive nature. To a lesser extent, also present were other legumes including *Zornia* sp. (Zsp) and *Alysicarpus sp.* (Asp) (Table 3.2).

The final visual assessment of species diversity is shown in Tables 3.3a and 3.3b; in general, grazing appeared to increase species diversity when compared to initial assessments (Table 3.2 vs. Tables 3.3a and 3.3b). *Dactyloctenium aegyptium* (Da) and

Panicum laetum (Pl) were the dominant grass species. The dominance of *Dactyloctenium aegyptium* (Da) after severe grazing can be attributed to its morphological characteristic of having meristematic tissue (areas of rapid cell division) located close to the ground where it is protected from being removed by the grazing animal. Hiernaux and Turner (1996) concluded that the effect of grazing on the vegetation in the Sahel region varied significantly and was affected more by growing condition and plant morphology than by grazing frequency. The *Bracaria* sp. (Bsp), dominant in part of the pasture prior to grazing, was less abundant at the end of the grazing season (Tables 3.3a and 3.3b). The disappearance of this species was evident in paddocks grazed to 3 cm, compared with paddocks grazed to 6 cm, indicating a possible grazing preference for this species. In general, more grass species were observed under the 6 cm residual height in comparison to the 3 cm residual height. Additionally, weedy species such as *Cassia tora* (Ct) were more frequently observed at the 3 cm residual height in comparison to the 6 cm residual height. These observations indicate that under severe defoliation, invasive unpalatable species showed a competitive advantage.

End of season species diversity for the ungrazed area of each paddock are shown in Tables 3.4a and 3.4b. The species observed on the ungrazed areas were similar to those shown in Tables 3.2, 3.3a and 3.3b. However, as shown particularly in replications 3 and 4, the diversity of plant species trended higher than in the grazed areas (Tables 3.3a and 3.3b). The plants observed in these paddocks included both new seedlings from reseeding and perennial plant growth after the dry season. In most cases, the presence of legume species trended more evident in the ungrazed areas than in the grazed areas, an indication of animal preference for legumes. These results are similar to those reported by

Watkins and Clements (1974) where selectivity led to grass domination in pastures especially when continuously grazed.

As expected, accumulated forage biomass increased with time ($P = 0.043$) (Fig. 3.5). The highest accumulation occurred (50% increase) between August 1 and August the 19. This large increase in biomass (almost 2000 kg ha^{-1}) can be attributed to the above average precipitation in August (Fig. 3.2). The yield increment was minimal in September while a small increase in forage biomass was observed in October (Fig. 3.5). Percent protein was higher initially ($P = 0.0113$) (August 1) and started declining in mid August and remained low until October. An increase in percent protein was observed in November probably due to the new growth promoted by the precipitation in October (Fig. 3.6 and 3.2). Percent acid detergent fiber increased with time ($P < 0.0001$) (Fig. 3.7) and declined in October for the same reason observed by the increase in percent protein in November. The change in forage quality can be attributed to the growing conditions (precipitation) and the change in botanical composition (legumes vs grasses).

Siragourou location

The initial ground cover of the grazing area in the Siragourou location was much less than at the Nérékoro location. Across treatments, the percent ground cover, ranged from less than 30% to 60% (Fig. 3.8). At the end of the grazing season the grazed pasture had significantly less ground cover than at the beginning of the grazing season. The grazed areas at both the 3 and 6 cm residual heights had had less than 30 % ground cover. This was considerably less ($P < 0.0001$) than the initial observation and the percent ground cover observed in the ungrazed area (Fig. 3.8). In most cases, the legume *Zornia* sp. (Zsp) was the most dominant species, followed by the grass *Bracaria* sp. (Bsp) (Table 3.5).

Among the weedy types of plant species, *Cassia tora* (Ct) was most abundant (Table 3.5). As mentioned above, *Cassia tora* (Ct) is only marginally palatable to livestock. Animals consume *Cassia tora* (Ct) at the vegetative stage and in the absence of more desirable forage. Other grasses found in this area in order of abundant to rare, were *Dactyloctenium aegyptium* (Da*), Microchloa indica* (Mi)*, Panicum laetum* (Pl), and *Tribulus terrestris* (Tt). *Dactyloctenium aegyptium* (Da) and *Panicum laetum* (Pl) are characterized as high quality palatable forages while *Microchloa indica* (Mi) is less desired by the grazing animals. The legume *Alysicarpus* sp (Asp) had frequent to rare appearances in these pastures.

The legume *Zornia* sp. (Zsp), observed early in the grazing season, remained dominant at the end of the season. However, a shift in botanical composition to grasses in place of this legume was evident (Tables 3.6a and 3.6b). The grasses *Schoenfeldia gracilis* (Sg) and *Eragrostis* sp (Esp) were dominant compared to the *Bracaria* sp (Bsp) that was observed in abundance earlier in the season. Both *Schoenfeldia gracilis* (Sg) and *Eragrostis* sp (Esp) are highly desired, good quality forage crops. However, these grasses are late maturing compared to the other plant species adapted to the area. Also, excessive primary growth and new growth from seeds could have caused the relative abundance of these two grasses. Due to abundant available forage, the result of excessive moisture during the 2003 grazing season, forge production exceeded animal need, thereby causing under utilization of plant species that are highly desirable at vegetative/less matured stages, such as *Schoenfeldia gracilis* (Sg) and *Eragrostis* sp. (Esp). At a mature stage (plants with seedhead), animals do not graze these two species, which explains the relative abundance of these plants at the end of the 2003 grazing season.

The cause of the botanical shift at this location could be attributed to grazing preference and forage abundance, which exceeded animal need, rather than to treatment effects (i.e., residual height). At the end of the growing season, all the grasses turned brown with the exception of the legume *Zornia* (Zsp) and a few broadleaf weeds. Regardless of soil moisture and temperature, annual grasses in this climate undergo senescence, the process of plant degeneration that generally occurs at the end of the growing season in order to produce seeds for the following season.

Visual evaluation of ungrazed areas revealed differences from the grazed areas (Tables 3.6a and 3.6b vs. 3.7a and 3.7b at chapter end). In most cases, regardless of treatments, both grasses and legumes appeared at similar frequencies in the ungrazed areas. In addition to grass/legume compositions, there were more plant species than in the grazed areas (Tables 3.7a and 3.7b). At both locations, due to the unseasonably wet growing season, forage production (but not quality) was maintained at the highest level throughout the growing season.

The accumulated dry matter yield at the Siragourou location was numerically less than the Nérékoro location (statistical anlyses were not performed to test location as an effect). By the end of the grazing season, this difference in biomass between the two locations was over 1000 kg ha^{-1} (Fig. 3.5 vs Fig. 3.9). Accumulated forage biomass yield increased with time ($P = 0.0337$) (Fig. 3.9). However the increase in biomass from August 1 to August 19 was much less than that of the Nérékoro location. Percent protein decreased as the grazing season progressed to the end ($P < 0.0001$) (Fig. 3.10). The decrease in percent protein from August 1 to November 3rd was 18.5 to 6.8 which was over 60%. Inversely, percent ADF increased 28 to 49% ($P < 0.0001$) from August to

November (Fig. 11). The decrease in percent protein and the increase in percent ADF with time is a reflection of plant maturity (lignifications).

Animal performance

Nérékoro and Siragourou locations

During the first week of November, the animals were removed from the pastures and weighed. The animals gained 1 to 3 kg for the season. For the Nérékoro location, there was only a slight numerical difference in weight gain between treatments (Table 3.8). According to the field technicians, the animals were heavier during August through mid-October, but might have lost weight towards the end of the grazing season due to poor forage quality. Breman and Cisse (1977) reported that annual plants with very short growing cycles mature faster and therefore become undesirable. Although forage biomass was high, the forage quality declined with the decrease in leaf to stem ratio and increase in seed head production. Generally, such unpalatable forages are high in fiber and low in crude protein and soluble sugars. If animals were weighed on a monthly basis instead of at the end of the grazing season, the assessment of treatment effects and overall animal performance probably would have been different from the current results. Although the original plan was to weigh the animals at the end of each cycle (after animals had gone through cycle of eight pegs/paddocks per treatment), due to the excessive forage growth during the 2003 growing season (driven by excessive rainfall), none of the animals went through all the eight grazing areas/paddocks. By the end of the grazing season two or three paddocks/treatment remained ungrazed for treatment one (where animals grazed to 3 cm residual height). Animals grazing to the 3 cm residual height moved more slowly through the cycle than those grazing to 6 cm residual height. As evidenced by the excessive forage mass left ungrazed this growing season, each pasture paddock could have carried two animals instead of one animal peg^{-1}. Also, where animals grazed to the 3 cm residual height, a trend was observed for the grazing effect to be more severe on most plant species (less re-growth and more bare ground) than paddocks grazed to the 6 cm residual height. The effect of the 3 cm grazing height on animal performance was more evident at the Siragourou location than at the Nérékoro location (ungrazed % ground cover – grazed % ground cover were 48 and 37% for Nerekoro and Siragourou, respectively), as shown by weight loss of one animal (Table 3.9). In contrast, animals grazing to 6 cm residual height gained (numerically) the most compared to the residual height of 3 cm at this location.

Summary and conclusion

In areas with unpredictable rainfall and poor soil fertility (Table 3.10), maintaining vegetative cover and the re-growth/persistence of forages is highly critical. The growing season is 80 to 90 days, with an average of 41 wet days and rainfall totals varying between 203 mm and 610 mm. The lack of pasture and forage resources has been a growing problem in the region. With rapidly disappearing perennial forages, annual grasses and some legumes have become the dominant species in the region. The overall objective of this study was to improve pasture resources and increase feed production.

The research indicated that response to intensive grazing was highly dependent on the morphological characteristics of the plant species. Plants with a horizontal growth pattern were able to re-grow at a faster rate after being defoliated to 3 cm stable height than more upright types of plants. This was mainly because the growing point (the site of rapid cell division) on the horizontal plants is close to the ground and out of danger of being removed by the grazing animal. It is critical that these tissues be close to the soil surface to escape damage during defoliation and thus permit re-growth. Plants with an upright growth habit are more sensitive to defoliation, and are slower to recover than plants with horizontal growth patterns. At the end of the growing season, the less frequent plant species found were those with upright growth habits that also happened to be highly desired (selectively grazed) by the animals.

The short and long term productivity and persistence of annual plants under natural conditions are by far more challenging than the management of perennial forbs, grasses or shrubs. The seasonal survival and regeneration of these annual grasses are solely dependent on self-reseeding. Therefore, the management of these types of grass swards needs to focus on the importance of the rest period and defoliation heights. The rest period between defoliation needs to be long enough to allow sufficient re-growth for grazing as well as reseeding. This time period can be shorter when rainfall is in excess, as it was in 2003, because it allows rapid re-growth compared to drought conditions where plant growth and persistence are severely limited. The data showed that close grazing of these annual plants will cause a shift in botanical composition that consists of redistribution and replacement of the more desirable grasses by more weedy types of plants. Based on in-season observations, the 6 cm compared with the 3 cm grazing height would promote re-growth within the same season and possibly allow the plant to reseed for the following growing season. Accumulated forage yield increased with time while forage quality declined. Seasonal weight gain of animals showed little difference among treatments. Quality of the forage rather than quantity might have contributed to the poor performance of the grazing animals. Our grazing management also may have contributed to low animal weight gains. Due to high forage production in 2003, animals stayed in one paddock for an extended period of time. Consequently, the average grazing period was 20 and 27 days for the 3 and 6 cm treatments, respectively, which was much longer than expected. This restricted animal movement (depended on residual height), and the decline in forage quality in subsequent paddocks may have caused this low animal weight gain. In order to take advantage of fast growing, short cycled annual plants, animals need to be rotated among paddocks more frequently.

Regardless of the dominant effects of the highly variable environmental conditions of the Sahel regions of Africa, the basic knowledge of the response of annual grasses to defoliation can make a big difference in maintaining in-season productivity and long term persistence of these grasses.

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List of Tables

Table 3.1. Plant height taken prior to initiation of the grazing experiment for the Nérékoro and Siragourou locations, Mali (West Africa), August, 2003

Nérékoro

Rep	Trt	Plot	Plant height (cm) ←measurements→	Average
1	1	1	10.5, 8, 5, 16, 10.5	10
1	2	1	27, 8, 7, 10, 28	16
2	2	1	10.5, 8, 5, 10, 7	8.1
2	1	1	8, 10.5, 8, 12, 4	8.5
3	1	1	8, 12, 6, 7, 6	7.8
3	2	1	6.5, 17, 9.5, 17, 17	13.4
4	2	1	8, 15.5, 8.2, 27.5, 14.5	14.74
4	1	1	16, 16.5, 7, 8, 11, 38	16

Siragourou

Rep	Trt	Plot	Plant height (cm) ←measurements→	Average
1	1	1	10.5, 8.2, 13, 6, 14	10.34
1	2	1	8.5, 5.5, 15.5, 10.5, 37	15.4
2	2	1	18, 31.5, 8, 6, 9	14.5
2	1	1	11, 9.5, 10, 5.5, 7	8.6
3	1	1	11.5, 10, 8, 39, 7.5	15.2
3	2	1	18.5, 31.5, 14, 19, 19	20.4
4	2	1	8, 8, 4, 12, 6.5	7.7
4	1	1	3.5, 6, 4, 8.5, 4	5.2

Table 3.2. Initial visual evaluation (1st paddock) of botanical composition for the **Nérékoro location**, Mali (West Africa), August 2003.

				COMPOSITION (%)			FORAGES				
Rep[a]	Trt[b]	Pr[c]		Grass	Legume	Weed	D[e]	A[f]	F[g]	O[h]	R[i]
1	1	1		100	0	0	Da	Pl			
1	1	1		100	0	0	Pl	Da			
1	2	1		95	0	5	Da, Pl	Ct			
1	2	1		100	0	0	Da		Pl		
2	2	1		100	0	0	Da, Pl		Csp		Pl
2	2	1		100	0	0	Da, Bsp				
2	1	1		100	0	0	Da	Pl			Esp
2	1	1		100	0	0	Da		Pl		
3	1	1		100	0	0	Da		Pl		Zsp
3	1	1		100	0	0	Da			Pl	Esp
3	2	1		100	0	0	Da	Bsp			Pl
3	2	1		99	1	0	Da	Bsp			Pl
4	2	1		99	1	0	Pl	Da			Asp
4	2	1		100	0	0	Bsp	Pl, Da			
4	1	1		100	0	0	Csp	Pl	Bsp	Da	
4	1	1		100	0	0	Da	Pl			

Rep[a] = Replication; Trt[b] = Treatment (1 = grazed to 3 cm stubble height; 2 = grazed to 6 cm stubble height) ; Pr[c] = Pasture; Gr.[d] = Ground cover; D[e] = Dominant; A[f] = Abundant; F[g] = Frequent; O[h] = Occasional; R[i] = Rare

Abrevations:

Grasses: Dactyloctenium aegyptium: Da; Panicum laetum: Pl; Eragrostis sp.: Esp.; Bracaria sp.: Bsp.

Legumes:Zornia: Zsp. ;Alysicarpus sp.: Asp.;.Cassia tora: Ct

Table 3.3 Final visual evaluation of botanical composition of the **grazed area**, **Nérékoro location**, Mali (West Africa), November 2003.

COMPOSITION, %							FORAGES				
Rep[a]		Trt[b]	Pl[c]	Grass	Legume	Weed	D[d]	A[e]	F[f]	O[g]	R[h]
1		1	1	80	20	0	Pl	Da	Cor		Ipo
1		1	2	90	10	0	Da	Dl			
1		1	3	99	1	0	Da	Dl			
1		1	4	100	0	0	Da	Dl, pp			
1		1	5	25	0	75	Ct	Dl	Da	Cor	Sid
1		2	1	98	1	1	Pl, Da				Cor
1		2	2	97	3	0	Pl	Da	Bsp		Cor, Isp
1		2	3	98	2	0	Da	Dl		Pl	
1		2	4	100	0	0	Da	Dl			
1		2	5	90	8	2		B.sp	Da	Ct	
2		1	1	99	1	0	Pl, Da			B.sp	Ipo
2		1	2	90	10	0	Pl	Da	Cor	Isp	
2		1	3	100	0	0	Da	Dl			
2		1	4	100	0	0	Da	Pl	B.sp.		
2		1	5	100	0	0	Da		Dl		Et
2		2	1	95	5	0	Pl, Da				Isp
2		2	2	98	2	0	Da	Pl			Isp, Cor
2		2	3	99	0	1	Pl, Da			Esp	
2		2	4	100	0	0	Da				
2		2	5	100	0	0	Da	Dl	Pl		
3		1	1	99	1	0	Da	Pl	B.sp	Sg	Et
3		1	2	98	2	0	Da	Pl			Ipo
3		1	3	90	10	0	Da	Pl		Bro	Et.
3		1	4	100	0	0	Da	B.sp			
3		2	1	90	5	5	Da	B.sp		Ipo	Cor
3		2	2	90	10	0	Da	B.sp	Isp	Dl	
3		2	3	94	1	5	Da	Esp, Pl			Ct
3		2	4	100	0	0	Da	Pl			

Rep[a] = Replication; Trt[b] = Treatment; Pl[c] = Paddock; D[d] = Dominant; A[e] = Abundant; F[f] = Frequent; O[g] = Occasional; R[h] = Rare

Abbreviations:

Grasses: Dactyloctenium aegyptium: Da;Panicum laetum: Pl;Eragrostis sp.: Esp.;Bracaria sp.: B.sp.;pennisetum pdicellatum (pp); Brachiaria ramose (Bro); Schoenfeldia gracilis: Sg;

Forbs: Ipomea sp.: Isp.;Cassia tora: Ct ; Corchorus tridens (cor); sida alba (Sida)

Table 3.3b. Final visual evaluation of botanical composition of the **grazed area**, **Nérékoro location**, Mali (West Africa), November 2003 (cont.)

COMPOSITION, %							FORAGES				
	Rep[a]	Trt[b]	Pl[c]	Grass	Legume	Weed	D[d]	A[e]	F[f]	O[g]	R[h]
	4	1	1	95	5	2	Pl	Da		Dal	Cor, Isp
	4	1	2	100	0	0	Da	Pl	B.sp		
	4	1	3	98	1	1	Da	Pl			
	4	1	4	95	5	0	E.sp	Da	Isp		
	4	2	1	98	2	0	Da	B.sp		Pl	Cor
	4	2	2	98	1	1	Da	Pl		Ct, Ipo	
	4	2	3	88	2	10	Da	Pl		B.sp	Cor, Isp
	4	2	4	0	100	0	Isp				

Rep[a] = Replication; Trt[b] = Treatment; Pl[c] = Paddock; D[d] = Dominant; A[e] = Abundant; F[f] = Frequent; O[g] = Occasional; R[h] = Rare

Abbreviations:

Grasses: Dactyloctenium aegyptium: Da;Panicum laetum: Pl;Eragrostis sp.: Esp.;Bracaria sp.: B.sp.;pennisetum pdicellatum (pp); Brachiaria ramose (Bro); Schoenfeldia gracilis: Sg;
Forbs: Ipomea sp.: Isp.;Cassia tora: Ct ; Corchorus tridens (cor); sida alba (Sida)

Table 3.4a. Final visual evaluation of botanical composition of the **ungrazed area,** the **Nérékoro location**, Mali (West Africa), November 2003.

COMP0SITION, %							FORAGES				
Rep[a]		Trt[b]	Pl[c]	Grass	Legume	Weed	D[d]	A[e]	F[f]	O[g]	R[h]
1		1	1	100	0	0	Pl	Da			
1		1	2	98	2	0	Pl	Da	Cor		Isp
1		1	3	10	0	0	Da	Dl		E.sp	
1		1	4	100	0	0	Da	Pl, Dl			
1		1	5	90	10	0	B.sp	Dl		Da	Cor, Et, St
1		1	6	50	49	1	Dl		Ct	Ipo	Cor, St
1		1	7	88	1	0	B. sp	Da		E.sp	Cor
1		1	8	90	10	0	Da	Dl		B.sp	Cor. Isp, St
1		2	1	100	0	0	Dl	Da	E.sp, Dl		
1		2	2	100	0	0	Da	Dl			
1		2	3	98	1	1	Pl	Da	Dl		
1		2	4	100	0	0	Da				
1		2	5	80	20	0	Da	Dl	Tp		
1		2	6	85	15	0	Da		E.sp	Bsp	
1		2	7	80	20	0	B.sp	Dl	Da, Tp	Cor	
1		2	8	90	10	0	Da	Dl	E.sp	Cor	Cyp
2		1	1	100	0	0	Da, Pl				
2		1	2	100	0	0	Da		Dl	E.sp	Cl
2		1	3	99	1	0	Da		B.sp	Pl, Dl	Isp
2		1	4	100	0	0	Da	Dl	E.sp		
2		1	5	100	0	0	Da				
2		1	6	75	20	5	Dl	B.sp	Da	St	
2		1	7	100	0	0	Da	Dl, Et			
2		1	8	99	0	1	Dl, Da		B.sp	E.sp	
2		2	1	97	2	1	Pl, Da				Z.sp, Cor
2		2	2	100	0	0	E.sp	Da, Pl			
2		2	3	99	1	0	Pl, Da	Dl			Isp
2		2	4	94	5	1	Da	Pl		Ipo	
2		2	5	100	0	0	Da	B.sp		E.sp, Cyp	
2		2	6	60	37	3	Dl		Pl	Tp	Isp,Cor
2		2	7	98	2	0	Da	E.sp		Sg	Ct, Isp
2		2	8	98	2	0	Da	E.sp		Sg	Ct, Isp

Grasses: Dactyloctenium aegyptium: Da;Panicum laetum: Pl;Eragrostis sp.: Esp.;Bracaria sp.: B.sp.;pennisetum pdicellatum (pp); Brachiaria ramose (Bro); Schoenfeldia gracilis: Sg; Setaria sp: St; Cloris sp: Cl .**Forbs**: Zornia (Zsp); Ipomea sp.: Isp.;Cassia tora: Ct ; Corchorus tridens (cor); sida alba (Sida); Cyperus sp. (Cyp) grasslike weed; tephrosia sp: Tp

Table 3.4b. Final visual evaluation of botanical composition of the **ungrazed area,** the **Nérékoro location**, Mali (West Africa), November 2003 (Cont).

COMPOSITION (%)							FORAGES				
Rep[a]	Trt	Pl[c]		Grass	Legume	Weed	D[d]	A[e]	F[f]	O[g]	R[h]
3	1	1		100	0	0	Da	Pl	B.sp	Sg	E.sp
3	1	2		98	2	0	Pl	Da	B.sp		Isp, Cor
3	1	3		95	5	0	Da, Pl	Dl		Sg	Za, St
3	1	4		90	0	20	Da	Dl, Pl	E.sp.		
3	1	5		80	15	5	Dl, Da	Pl, B.sp	Isp,Cyp		Coc
3	1	6		60	20	20	B.sp	Dl, Da	Isp		
3	1	7		89	1	10	Da	B.sp	Gl		Cor
3	1	8		50	0	50	Da	B.sp	Pl		
3	2	1		95	5	0	Da	Pl	B.sp, Dl	Isp, Zsp	
3	2	2		80	10	10	Da	Pl	Isp, Dl	E.sp, Gl	
3	2	3		82	3	15	Dl	Da, Pl	B.sp		Isp
3	2	4		100	0	0	Da	Bsp.Pl	Dl		
3	2	5		30	10	60	Da	B.sp	Dl	Ipo	
3	2	6		93	2	5	Da	B.sp, Dl			Cor, Isp
3	2	7		88	2	10	Da	Dl		Pl	Isp
3	2	8		98	2	0	Da	Dl	Pl	E.sp	Isp
4	1	1		95	5	0	Da	Pl	Dl	Cor	Cl
4	1	2		85	5	10	Dl, Da		Pl	Isp, Gl	
4	1	3		99	1	0	Da	Dl	B.sp	Gp, E.sp	Ipo
4	1	4		0	15	85				Ipo	
4	1	5		85	5	10	B.sp	Pl	E.sp	Ipo	Ct
4	1	6		99	1	0	B.sp	Dl	Da	Pl	Ipo
4	1	7		95	5	0	Da	Pl, B.sp		Isp	Tp
4	1	8		95	5	0	Da	Dl, B.sp	Tp	Isp, St	
4	2	1		80	15	5	Pl	Da	Tp, B.sp	Isp	Z, Ct
4	2	2		75	10	15	Dl	Da, Pl		Isp	Cor, St
4	2	3		98	2	0	Da	B.sp	Pl, Isp		Sg
4	2	4		30	70	0	Isp	B.sp	Da	Cl, Cor	Sg
4	2	5		90	10	0	Ei	Da	Ipo		
4	2	6		94	5	1	Dl	Da	Cl, Esp	B.sp, Cor, Pl	
4	2	7		96	4	0	Pl, Dl	B. sp	Cl, Da	Z.sp, Ct	
4	2	8		98	1	1	Dl	Da	Gl		Isp

Grasses:Dactyloctenium aegyptium: Da;Panicum laetum: Pl;Eragrostis sp.: Esp.;Bracaria sp.: B.sp.;pennisetum pdicellatum (pp); Brachiaria ramose:Bro; Schoenfeldia gracilis: Sg; Setaria sp: St; Cloris sp: Cl .Forbs: Zornia (Zsp); Ipomea sp.: Isp.;Cassia tora: Ct ; Corchorus tridens (cor); sida alba (Sida); Cyperus sp. (Cyp) grasslike weed; tephrosia sp: Tp;

Table 3.5. Initial visual evaluation (1st paddock) of botanical composition for the **Siragourou location,** Mali (West Africa), August 2003.

			COMPOSITION (%)				FORAGES				
Rep[a]	Trt[b]	Pl[c]		Grass	Legume	Weed	D[d]	A[e]	F[f]	O[g]	R[h]
1	1	1		40	60	0	Zsp.	Da	Mi, Asp		
1	1	1		15	80	5	Zsp.	Mi			
1	2	1		40	60	0	Zsp.	Msp.	Dsp.		
1	2	1		15	80	5		Zsp.,Mi			Pl
2	2	1		10	90	0	Zsp.		Bsp.	Mi	Asp.
2	2	1		30	50	20	Dsp	Bsp., Ct, Cn	Da, Zsp.		Esp.
2	1	1		5	95	0	Zsp.		Bsp.		Mi, Asp
2	1	1		20	75	5	Zsp.		Mi		Bsp, Asp
3	1	1		20	80	70	Bsp.	Zsp.	Asp.	Mi	
3	1	1		30	60	70		Zsp,Bsp			Tt, Isp.
3	2	1		10	90	0	Bsp.	Zsp.			Asp, Ul
3	2	1		50	30	20	Bsp.			Pl, Zsp.	Asp.
4	2	1		33	67	0	Bsp.		Zsp.		
4	2	1		60	35	5					Zsp, Mi
4	1	1		10	90	0	Zsp.	Bsp.			Mi
4	1	1		10	90	0	Zsp.				Mi

Dominant weedy species Ct, Cn

Rep[a] = Replication; Trt[b] = Treatment; Pl[c] = Paddock; D[d] = Dominant; A[e] = Abundant; F[f] = Frequent; O[g] = Occasional; R[h] = Rare

Abrevations:

<u>Grasses</u>: Dactyloctenium aegyptium: Da;Panicum laetum: Pl;Tribulus terrestris: Tt;Bracaria sp.: Bsp.;Microchloa indica: Mi; Digitaria sp.: Dsp.; Digitaria longitudinalis : Dl ; Tribulus terrestris: Tt

<u>Forbs</u>:Zornia: Zsp. ;Alysicarpus sp.: Asp. ;Urena lobata: Ul ; Ipomea sp.: Isp.Cassia tora: Ct ;Cassia nigricans: Cn

Table 3.6a. Final visual evaluation of botanical composition of the **grazed area**; for the **Siragourou location**, Mali (West Africa), November 2003.

COMPOSITION (%)							FORAGES				
Rep[a]	Trt[b]	Pl[c]		Grass	Legume	Weed	D[d]	A[e]	F[f]	O[g]	R[h]
1	1	1		100	0	0	Sg			B. sp	
1	1	2		40	60	0	Zsp.	Sg			Esp
1	1	3		2	98	0	Zsp.				Sg
1	1	4		10	90	0	Zsp.			Sg	B.sp
1	1	5		40	60	0	Zsp.			Sg	
1	1	6		30	70	0	Zsp.		Et		I. sp
1	2	1		100	0	0	Sg				
1	2	2		80	20	0	B.sp	Zsp.			Ao
1	2	3		40	60	0	Zsp., B.sp		Sg		Ao, Ms
1	2	4		0	100	0	Zsp				
1	2	5		10	90	0	Zsp		Sg		
1	2	6		15	85	0	Zsp		Sg		
1	2	7		60	40	0	Isp, Da			Esp, Sg	Sb
2	1	1		80	20	0	Zsp, Sg			Esp, Ao	Da
2	1	2		1	99	0	Zsp				Sg, Ao
2	1	3		1	99	0	Zsp				Sg
2	1	4		10	90	0	Zsp		B.sp		
2	1	5		20	80	0	Sg			Sg	
2	2	1		40	60	0	Zsp		Sg	B.sp	Esp
2	2	2		0	100	0	Zsp				
2	2	3		5	95	0	Zsp				
2	2	4		50	50	0					Zg, Esp
2	2	5		60	40	0	Sg	Zsp			
2	2	6		95	5	0		Sg			I.sp
3	1	1		85	15	0	B.sp	Pl, Zsp		Sg	Ct
3	1	2		80	0	20	B.sp				
3	1	3		15	85	0	Zsp				Sg, Esp
3	1	4		10	90	0	Zsp			Sg	
3	1	5		15	85	0	Zsp			Esp, Sg	B.sp
3	2	1		60	40	0	B.sp	Sg, Ao	Zsp		
3	2	2		50	50	0			Zsp, Sg		

Table 3.6b. Final visual evaluation of botanical composition, for the Siragourou location, November 2003 (cont.).

COMPOSITION (%)							FORAGES				
Rep[a]	Trt[b]	Pl[c]		Grass	Legume	Weed	D[d]	A[e]	F[f]	O[g]	R[h]
3	2	3		100	0	0	Sig				
3	2	4		80	20	0	Sg	Zg			
3	2	5		60	40	0	B.sp	Zg		Sg	
4	1	1		10	90	0	Zsp			Sg	B.sp
4	1	2		100	0	0	Sg				
4	1	3		100	0	0	Sg				
4	1	4		15	85	0	Zsp Ao	Pl			Ipo
4	1	5		10	90	0	Ig			Sg	
4	1	6		100	0	0	Esp				
4	1	7		40	60	0	Zsp	B.sp	Esp	Ipo, Cb	
4	1	8		55	45	0	Zsp	Esp, Sg			
4	2	1		100	0	0	Sg				
4	2	2		100	0	0	Sg		Et		
4	2	3		50	50	0	Zsp	B.sp, Sg			
4	2	4		95	5	0	Sg				Tp
4	2	5		98	2	0	Sg		Esp		Zsp
4	2	6		80	20	0	Sg	Zsp		Esp	
4	2	7		40	60	0	Zsp	Sg		Cb	

Rep[a] = Replication; Trt[b] = Treatment; Pl[c] = Paddock; D[d] = Dominant; A[e] = Abundant; F[f] = Frequent; O[g] = Occasional; R[h] = Rare

Abrevations:

<u>Grasses</u>: Dactyloctenium aegyptium: Da;Panicum laetum: Pl;Eragrostis sp.: Esp.;Bracaria sp.: Bsp.; Cenchrus biflorus : Cb; Schoenfeldia gracilis: Sg

<u>Forbs</u>: Zornia (Zsp); Ipomea sp.: Isp.;Cassia tora: Ct ; tephrosia sp: Tp; Ipomia vegans: Ig

Table 3.7a. Final visual evaluation of botanical composition of the **ungrazed area** the **Siragourou** location, Mali (West Africa), November 2003.

COMPOSITION (%)							FORAGES				
Rep[a]	Trt	Pl[c]		Grass	Leg	Weed	D[d]	A[e]	F[f]	O[g]	R[h]
1	1	1		100	0	0	Sg	Mi	Zsp		
1	1	2		98	2	0	Sg, Mi	B.sp	Esp		Ao, Z.sp
1	1	3		35	65	0	Zsp	Sg			
1	1	4		20	80	0	Zsp		Esp	Sg	
1	1	5		45	55	0	Zsp	B.stp	Esp		
1	1	6		10	90	0	Zsp		Sg		Esp, Isp
1	1	7		30	70	0	Zsp	Isp	Esp	Da	Ao, Cb
1	1	8		40	60	0	Zsp, Da				Cb, Esp
1	2	1		40	59	1	Zsp, Mi	Sg	Esp	Ao	
1	2	2		40	60	0	Zsp	Sg		B.sp	Ind. Sp
1	2	3		50	50	0	Zsp	Sg, B.sp			Ao, Esp
1	2	4		45	55	0	Zsp	Sg		Esp	
1	2	5		30	70	0	Zsp, Isp	Sg	B.sp		Esp, Ao, Dl
1	2	6		70	30	0	Isp, B.sp, Dl, Pl	Cb	Zsp	Ao, Br	
1	2	7		60	40	0	I.sp, Da	Zsp, Dl		Tp	
1	2	8		40	60	0	I.sp	Dl	Esp, Sg, Da		
2	1	1		40	60	0	Zsp	Sg	Esp	Da	
2	1	2		20	80	0	Sg	B.sp	Esp, Da		
2	1	3		5	95	0	Zsp				Esp, Sg, Iv
2	1	4		20	80	0	Zsp	B.sp	Ao	Sg	Cb
2	1	5		60	40	0	B.sp	Zsp	Isp	Cb, Sg	Iv
2	1	6		55	45	0	B.sp, Zsp		Esp		
2	1	7		55	45	0	Zsp Pl				Esp, Sg
2	1	8		60	40	0	Da	Zsp,, Pl	Dl		Esp, Cb,Iv
2	2	1		98	2	0	Mi	B.sp	Sg	Zg	Esp
2	2	2		50	50	0	Zsp, Sg		B.sp		Esp
2	2	3		35	65	0	Zsp	Sg			
2	2	4		20	80	0	Zsp		B.sp	Sg	Esp, Sb
2	2	5		85	15	0		Esp, Zsp			Cb
2	2	6		95	5	0		Sg			Isp
2	2	7		90	10	0	Sg			Cb, B.sp	Zg
2	2	8		45	55	0	Zsp		Esp, Sg	Sb, Da	I.sp

Table 3.7b. Final visual evaluation of botanical composition of the **ungrazed area** the **Siragourou location**, November 2003.

COMPOSITION (%)							FORAGES				
Rep[a]	Trt[b]	Pl[c]		Grass	Legume	Weed	D[d]	A[e]	F[f]	O[g]	R[h]
3	1	1		60	40	0	Sg, Zsp	B.sp		Esp	
3	1	2		40	60	0	Zsp	B.sp			
3	1	3		20	80	0	Zsp	Sg	B.sp		Iv
3	1	4		5	90	0	Zsp			Sg	
3	1	5		15	85	0	Zsp		Et		Sg
3	1	6		64	35	1	Sg	Zg		Cb Esp	I.sp
3	1	7		20	80	0	Zsp	Sg	Cb, Esp		
3	1	8		35	63	2	Zsp	Esp, B.sp	Pl	I.sp	Cb, Tp
3	2	1		50	50	0	Sg	Zg, Pl	Ind. Sp		Iv
3	2	2		40	60	0	Zsp	Sg	B.sp		
3	2	3		40	60	0	Zsp	Sg			Vi
3	2	4		40	60	0	Zsp	Sg	B.sp		Cb, Ao
3	2	5		30	70	0	Zsp	B.sp		Et, Sb	
3	2	6		65	35	0	Zsp		Esp	Cn	Pl,Isp, B.sp
3	2	7		10	90	0	Zsp	Sb	Esp Sg	Ao, Da	
3	2	8		5	95	0	Zsp		Esp, B.sp	Sb, Da	Sg
4	1	1		94	5	1	Sg			Zg	
4	1	2		98	1	1	Mic			Sg	
4	1	3		50	50	0	Sg, Zsp		Pl		Esp
4	1	4		90	10	0	Pl		Iv		Sg
4	1	5		95	5	0	Sg				Zsp, Iv
4	1	6		50	50	0	Zsp	Esp, Sg	Sb		Ao
4	1	7		40	60	0	Zsp	B.sp			
4	1	8		55	45	0	Zsp	Esp, Sg			
4	2	1		100	0	0	Cr	Sg		Esp	
4	2	2		80	20	0	Sg	Zsp			Iv
4	2	3		60	4 0	0	Pl	Da, B.sp	Zsp, Ao		
4	2	4		55	45	0	B.sp	Tf	Sg, Pl		
4	2	5		60	40	0	Esp, Zg	Sg	B.sp	Ao	
4	2	6		50	50	0	Zsp, Dl	Sg	Ao		Cb, Tp
4	2	7		0	100	0	Zsp				
4	2	8		20	80	0	Zsp		Sg, Da		Dl

Abrevations: Grasses: Dactyloctenium aegyptium: Da;Panicum laetum: Pl;Eragrostis sp.: Esp.;Bracaria sp.: Bsp.;Microchloa indica: Mi; Digitaria longitudinalis : Dl; Cenchrus biflorus : Cb; Schoenfeldia gracilis: Sg; Brachiaria ramosa: Br.**Forbs** :Zornia: Zsp. ; Ipomea sp.: Isp.; tephrosia sp: Tp; Ao?; Ipomia vegans: Iv; Indigofera sp. Ind. Sp; Valteria indica: Vi

Table 3.8. The influence of sheep grazing tethered at 3 and 6 cm residual canopy height on animal performance, **Nérékoro location** Mali, (West Africa).

Animal Tag #	Initial Weight (kg) July 31, 2003	Final Weight (kg) November 4, 2003	Seasonal Weight Gain (kg)	Average Daily Gain (g)
Treatment I (3 cm residual canopy height)				
2	21.00	24.00	3.00	32.00
3	18.00	19.50	1.50	16.00
4	18.00	20.50	2.50	27.00
7	18.00	19.00	1.00	11.00
Average	18.75	20.75	**2.00**	
Treatment II (6 cm residual canopy height)				
8	20.00	21.00	1.00	11.00
5	19.00	22.00	3.00	32.00
6	18.00	19.50	1.50	16.00
1	18.00	20.00	2.00	22.00
Average	18.75	20.63	**1.88**	

Table 3.9. The influence of sheep grazing tethered at 3 and 6 cm residual canopy height on animal performance, **Siragourou location** Mali (West Africa).

Animal Tag #	Initial Weight (kg) July 31, 2003	Final Weight (kg) November 4, 2003	Seasonal Weight Gain (kg)	Average Daily Gain (g)
Treatment I (3 cm residual canopy height)				
2	24.00	25.40	1.40	15.00
3	18.00	22.00	4.00	43.00
4	21.00	22.50	1.50	16.00
7	20.00	19.00	-1.00	---
Average	20.75	22.23	**1.48**	
Treatment II (6 cm residual canopy height)				
8	24.00	26.00	2.00	22.00
5	18.00	20.00	2.00	22.00
6	20.00	24.00	4.00	43.00
1	19.00	22.00	3.00	32.00
Average	20.25	23.00	**2.75**	

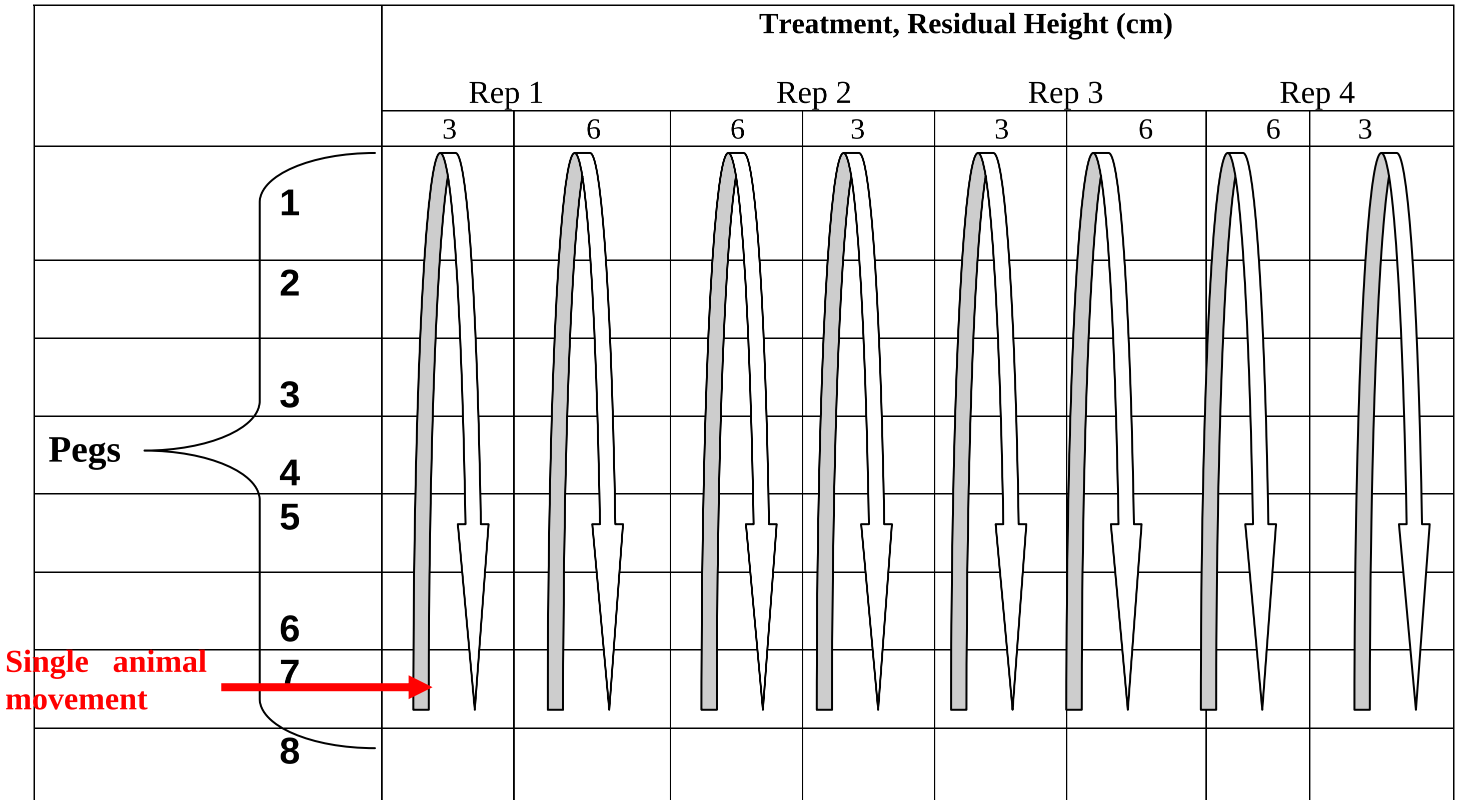
Table 3.10. Soil test results obtained from sites with different vegetations in pastures at two locations (Siragourou and Nerekoro) within the Madiama Commune, Mali (West Africa)

	Siragourou			**Nérékoro**			**Typical values for Mali soils**
Items	**Areas mostly legumes**	**Areas mostly *Cassia tora***	**Entire pasture**	**Areas mostly legumes**	**Areas mostly *Cassia tora***	**Entire pasture**	
pH (in water) pH (KCL)	5.10 4.29	5.36 4.70	4.74 4.15	6.25 5.83	7.20 6.55	6.50 5.98	5.0-5.5
Organic matter % C Nitrogen (Azote) %N	0.02	0.03	0.01	0.03	0.06	0.05	0.05
Total Phosphorus, ppm	13.00	15.42	13.00	14.73	41.41*	28.24*	7.0
CEC, meq/100g	1.76	2.67	2.02	3.71	3.58*	3.71	
Sodium (Na), ppm	0.09	0.18*	0.01	0.21*	0.09	0.17	0.01
Potassium (K), ppm	0.14	0.17	0.11	0.20	1.17	0.37	0.20
Calcium (Ca), ppm	0.59	0.97	0.51	1.43	1.97	1.34	0.70
Magnesium (Mg), ppm	0.37	0.52	0.29	0.87	1.13	0.32	0.40
Iron (Fe), ppm	30.76*	17.72	10.04	7.40	16.60	30.08*	20
Copper (Cu), ppm	0.52	0.20	0.28	-	0.12	0.48	-
Zinc (Zn), ppm	0.12	0.12	-	0.48	0.76	0.96	-
Manganese (Mn), ppm	8.80	18.40	9.40	14.36	15.52	21.56*	20

*Values with star questionable values being re-run for accuracy

List of figures

Fig. 3.1 Experimental layout of sheep grazing tethered for both Nerekoro and Siragourou locations, Mali (West Africa)



1. Animal pegged with 6-m long rope: Area/animal= 6^2 X 3.14= 113 m^2/animal
2. Total area per location: 113 X 64 [(area/animal) X (2 treatments) X (4 replications) X (8 pegs)] = 7232 m^2 = 0.7232 hectares per site.
3. The number of days animal stayed at each peg (record the date animal moved from peg to peg.
4. Plant height, ground cover evaluation and botanical composition at all pegs every time animal is moved.

Fig. 3.2 Sheep grazing tethered at the Nérékoro location within the Madiama Commune, Mali (West Africa)

Fig. 3. 3 Annual precipitations (mm) recorded for Madiama Commune, Mali (West Africa) from 1999-2003.

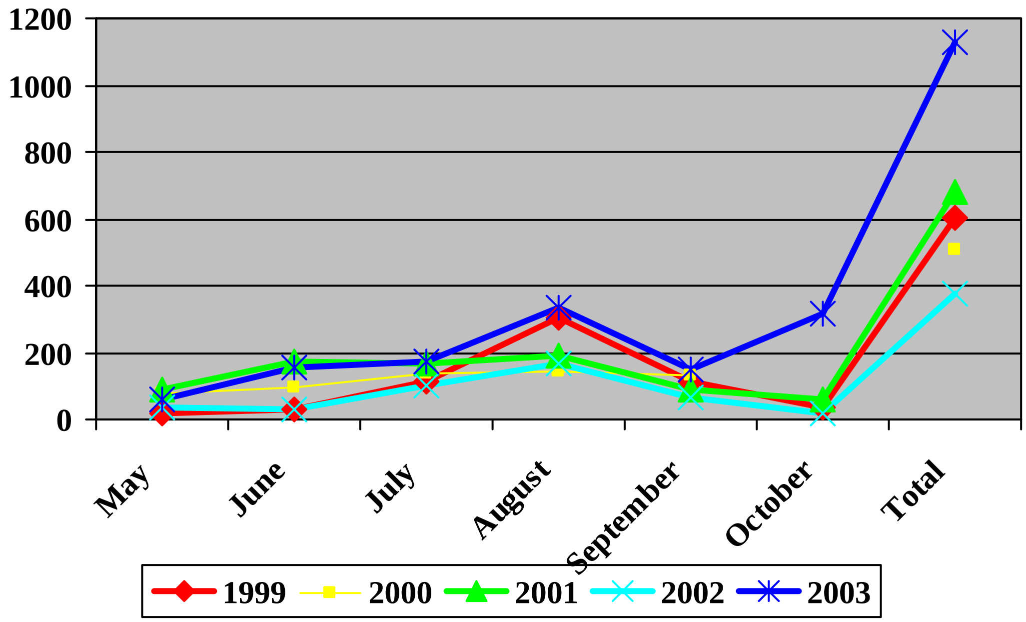


Fig. 3.4. Effect of treatment on percent ground cover of initial, grazed and ungrazed areas, Nérékoro location, Mali (West Africa), 2003

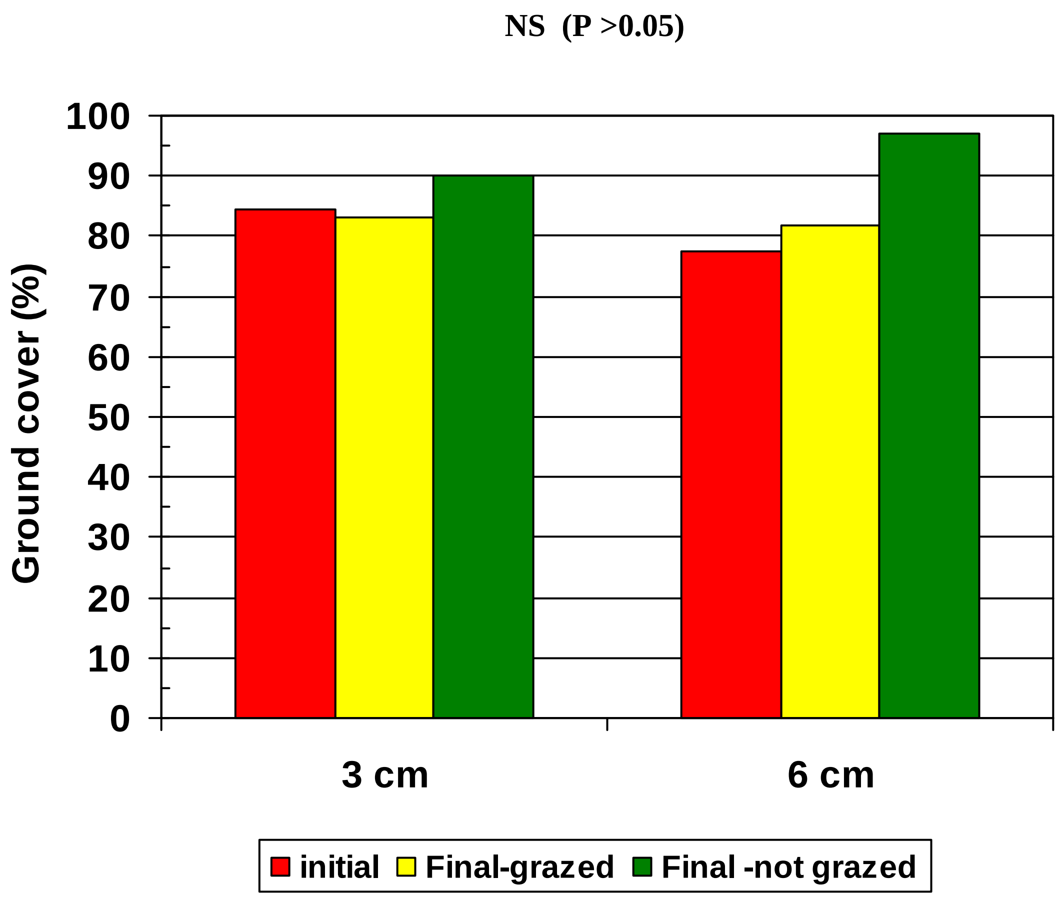


Fig. 3.5 Dry matter yield of forage harvested from the un-grazed area, **Nérékoro location,** Mali (West Africa), 2003

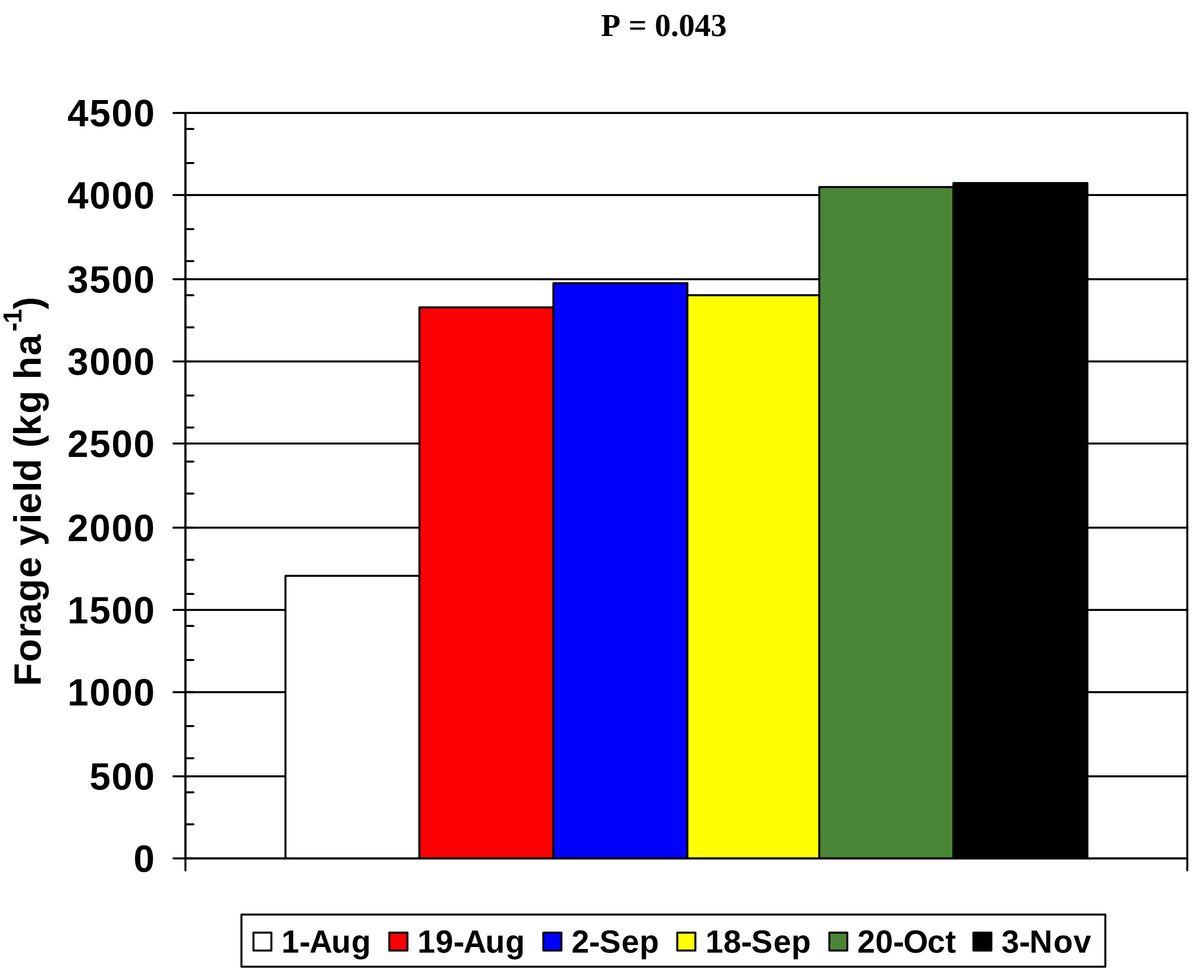


Fig. 3.6 Percent crude protein of forage harvested from the un-grazed area, **Nérékoro location,** Mali (West Africa), 2003

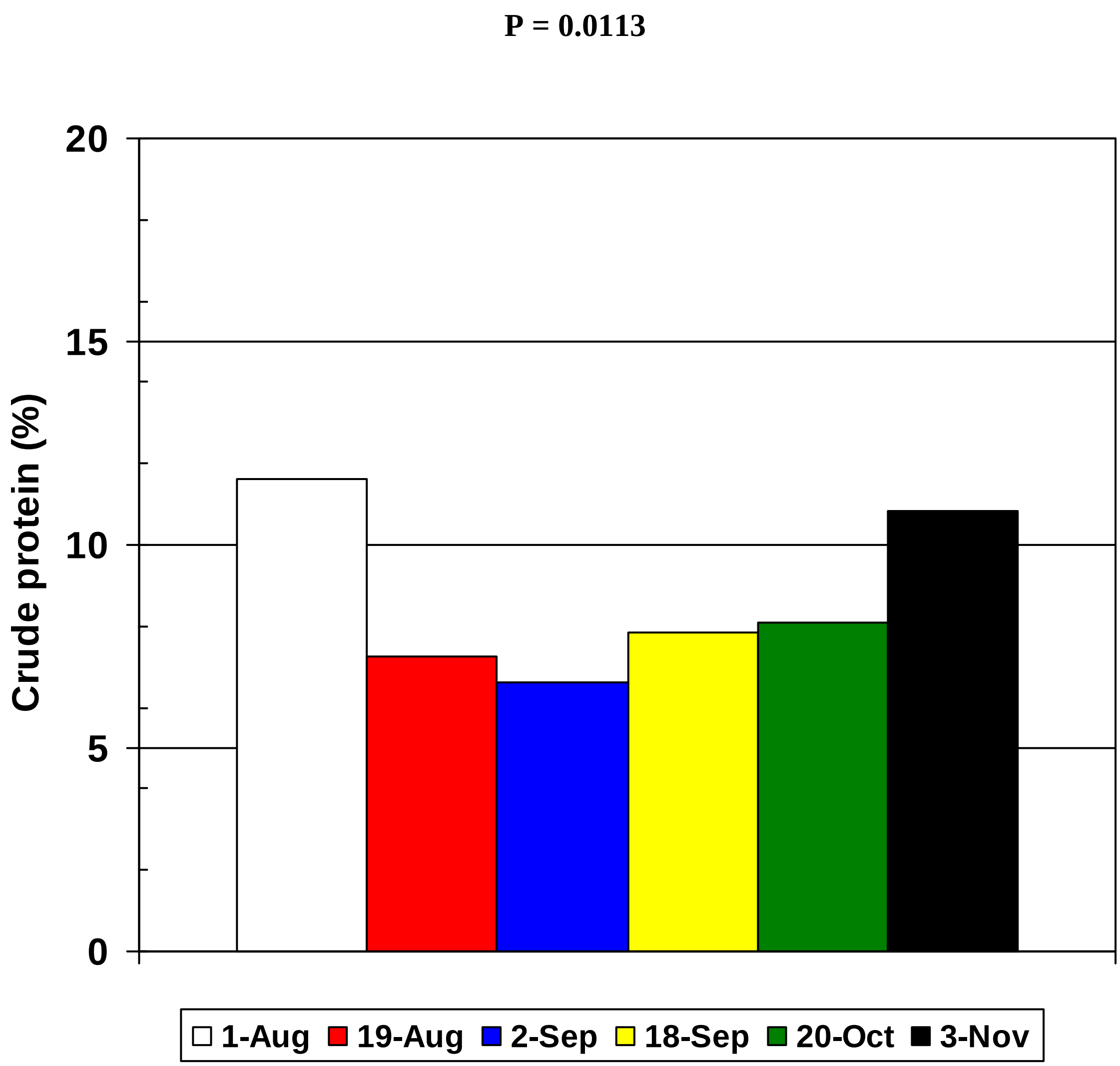


Fig. 3.7 Percent Acid detergent fiber (ADF) of forage harvested from the un-grazed area, **Nérékoro location,** Mali (West Africa), 2003

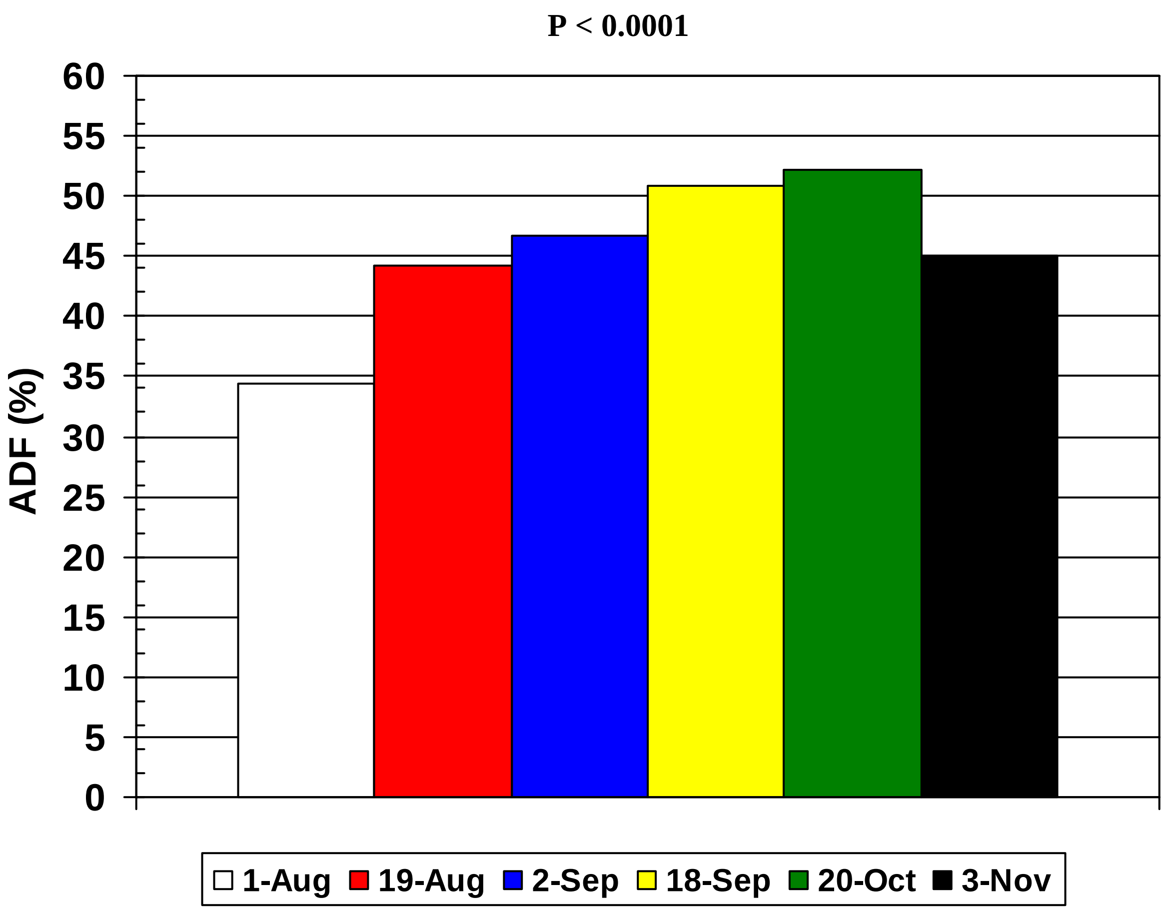


Fig. 3.8 Effect of treatment on percent ground cover of initial, grazed and ungrazed areas, **Siragourou location**, Mali (West Africa), 2003

NS (P > 0.05)

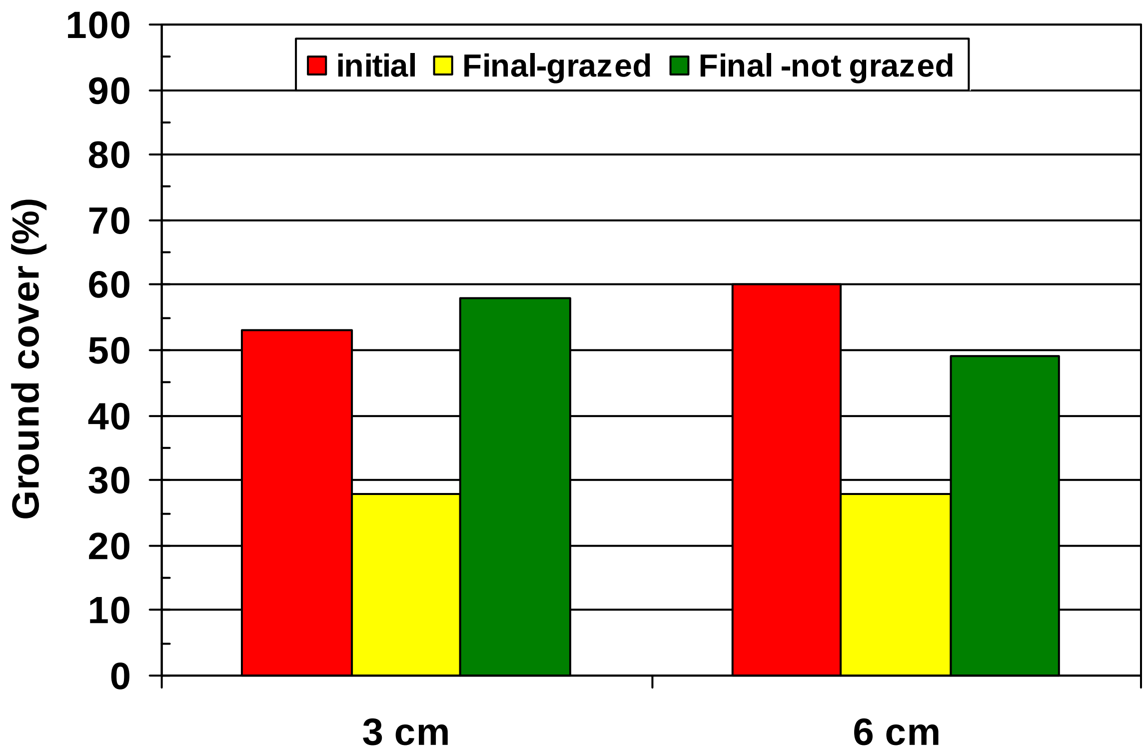


Fig. 3.9 Accumulated dry matter yield of forage harvesteded from ungrazed area, **Siragourou location**, Mali (West Africa), 2003

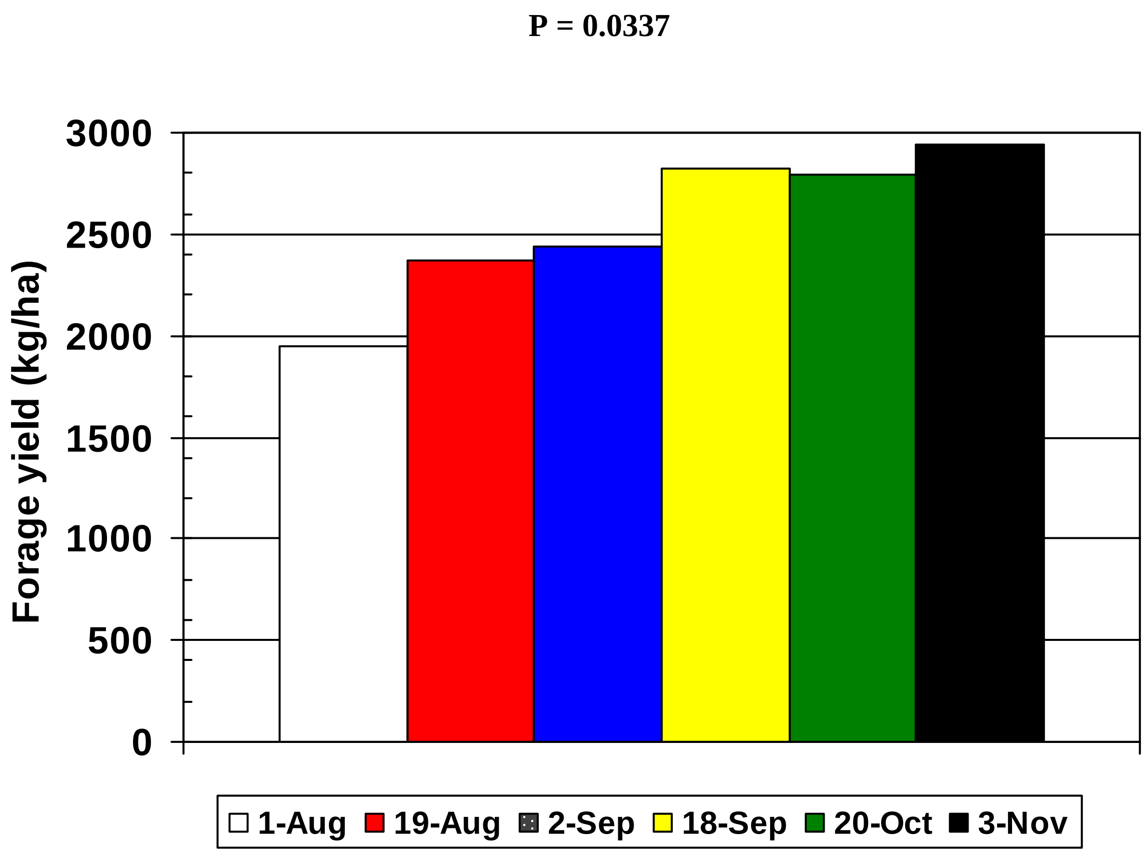


Fig. 3.10 Percent crude protein of forage harvested from ungrazed area, **Siragourou location**, Mali (West Africa), 2003

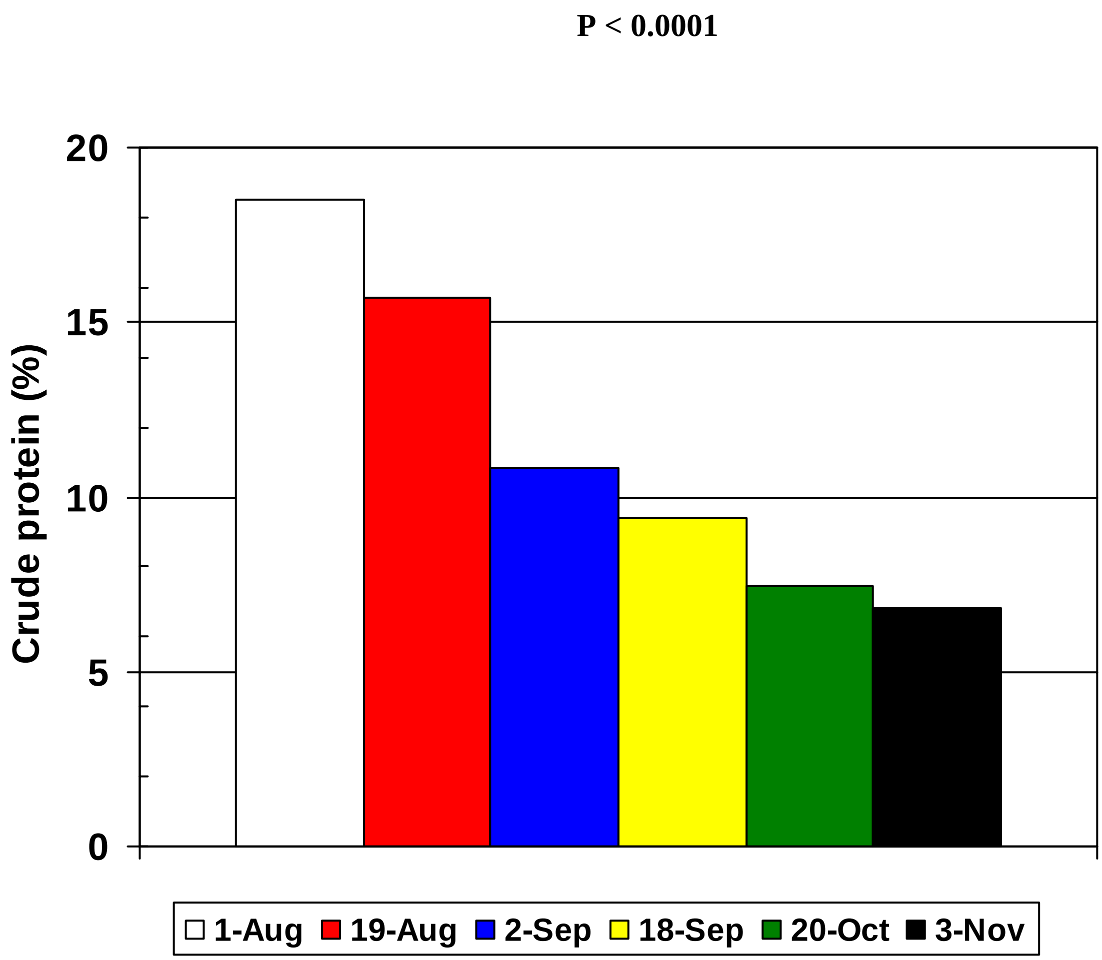
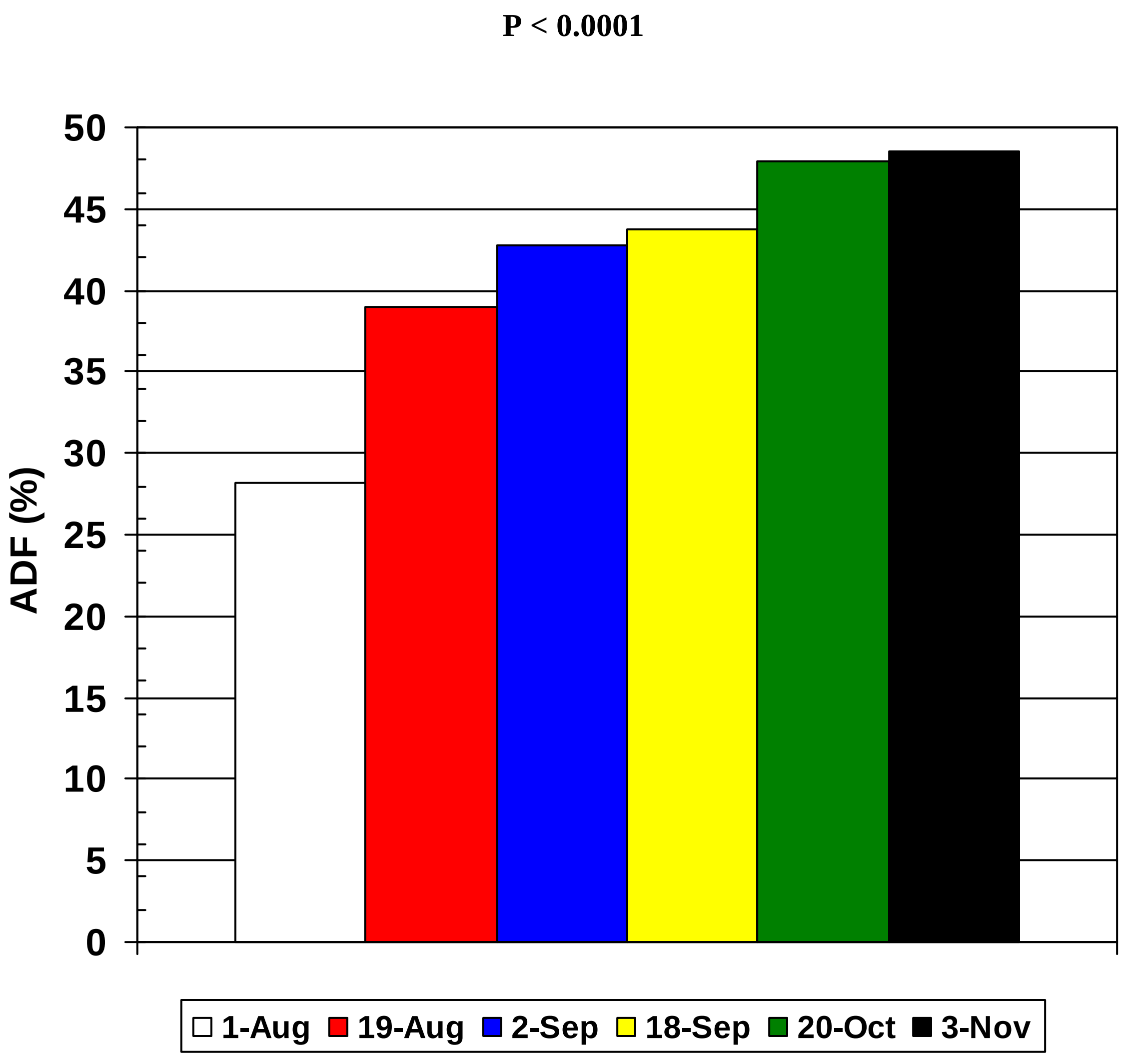


Fig. 3.11 Percent Acid detergent fiber (ADF) of forage harvested from the un-grazed area, **Siragourou location**, Mali (West Africa), 2003



Chapter IV

Dry Season Feed Supplements: The Potential Role of *Cassia tora*

Abstract

The lack of forage resources in the Sahelian region of Mali is a major constraint to food production and food sufficiency. *Cassia tora* is an annual weedy forb that widely grows throughout Mali during and after the rainy season. Its aggressive nature allows it to outcompete grasses, and its unpalatability for livestock, imposes more problems than potential benefits. The objectives of this experiment were: to evaluate the chemical characteristics and nutritive value (crude protein, *In vitro* dry matter digestibility, and fibers) of ensiled vs. fresh *Cassia tora*; and to examine the effect of additives (water or honey) and other forages (grasses) on the quality (chemical characteristics or nutritive value) of the ensiled material. *Cassia tora* with or without added treatments (water and honey for year 1; sugar and grasses for year 2) was ensiled for 60 or 90 days. *Cassia tora* was collected at a mature growth stage (year 1) and vegetative stage (year 2) from three locations in the Madiama commune of Mali. Prior to placing the chopped material in plastic bags for ensiling, sub-samples of fresh *C. tora* as well as the mixtures with additives were obtained for dry matter (DM) and chemical analysis (neutral detergent fiber (NDF), acid detergent fiber (ADF), and crude Protein (CP) as well as in vitro dry matter digestibility (IVDMD) and total digestible nutrient (TDN). After 60 or 90 days of ensiling, the silos were opened and samples for DM and chemical analysis were obtained. All samples were transported to the US for analysis. The ensiled material across treatments and locations had NDF varying from 48 % to 56 %, ADF from 34 % to 41 %, CP from 9 % to 10 %, and IVDMD from 53 to 64 % in year 1. The fresh material had NDF from 56 % to 57 %, ADF from 40 % to 42 %, CP from 9 % to 23 %, and in vitro dry matter digestibility from 52 to 54 %. *Cassia tora* even at its late stage of maturity could provide a good quality feed source with reasonably high nutrient content. Year 2 CP results were up to two fold year 1 results (15-22%) with much lower fiber values. These differences can be attributed to the time *C. tora* was harvested and the stage of maturity of the plant prior to ensiling. Honey or sugar improved the quality of the ensiled material. These results show that weedy species could provide with a good source of feed in the semi-arid tropics; *C. tora* could be a sustainable and economically feasible solution to feed shortages during the dry season in Madiama.

Introduction

Cassia (Senna) tora L., *foetid cassia*, *C. (S.) obtusifolia* L., sicklepod, coffee weed, etc., are very closely related annual weedy forb belonging to the family *Caesalpiniaceae* in the order Leguminosae (Cock and Evans, 1984). *Cassia* is a weed of 26 crops in 67 countries and is more prevalent in *Glycine max* (soybeans), *Arachis hypogaea* (peanuts), pastures, *Gossypium hirsutum* (cotton) and *Saccharum officinarum* (sugarcane) than other crops. *Cassia obtusifolia* commonly known, as coffeeweed, sicklepod, or coffee-pod, is the most prevalent species of *Cassia*, can reach heights of 1.8 to 2.1 m, and produces sickle-shaped seedpods. The teardrop-shaped leaves grow in clusters of 4 to 6 leaflets. It is often confused with *C. tora*. In fact, it is difficult to distinguish between the two (Brenan, 1958). Some investigators claim to have seen plants intermediate between the two species. Bhandari (1978) treated *C. tora* as the synonym of *C. obtusifolia.* Others distinguished the two on the basis of epidermal structure and seed analysis (Mall, 1957; Pandey, 1970; and Mathur, 1985). Randell (1995) discussed the possibility that *C. tora* evolved in Asia from *C. obtusifolia*. *Cassia obtusifolia* is well documented as a weed of peanuts and soybeans in the southern USA, and is widespread throughout the tropical world. *C. tora* is becoming increasingly prominent as a pasture weed in the Southwestern Pacific, Asia, and Africa. De Wit (1955) characterized *C. tora* as a weed species throughout the tropics, probably of South American origin. Singh *et al*. (1970) characterized it as a minor weed of various crops, but of greatest importance as a pasture weed and suggested that it became established in response to overgrazing. Hoveland *et al*. (1976) found that among other tropical legumes *C. occidentalis* L. and *C. obtusifolia* L. (sicklepod) were the most tolerant to low available soil P. For this reason *C. tora* may have an important role to play in soil fertility enhancement. However, due to its aggressive nature that excludes grasses from being grown with it or in the surrounding areas, and its unpalatability for animals, it may introduce more problems than potential benefits. In most cases, grazing animals are used to control undesired species in pasture by varying the stocking rate, but this option is not available since animals do not graze on fresh *C. tora* as it is unpalatable to all livestock. Since the use of herbicide to control this plant is unlikely in developing countries, alternatives are needed to reduce its spread or improve its quality (or acceptance) for animal feed.

Cassia as forage

Although *Cassia tora* is considered a poisonous plant, the toxic compound in *Cassia* has not been clearly defined. The seeds appear to exert their toxicity upon the skeletal muscles, kidney, and liver. The leaves and stem also contain toxin, whether green or dry. The plant can poison animals if they consume it in the field, in green chop, in hay or in grain containing the seed. Perkins and Payne (1985) suggest that anthraquinones found in the leaves are the toxic compounds of this plant. Others report that the seeds of the plant contain emodin, other anthraquinones and xanthones (Manjunath and Subbajois, 1930; Gupta and Sharma, 1965; Rangaswami, 1963). Tiwari and Behari (1972) have found anthraquinones in the roots of *C. tora*. Pal *et al*. (1977) have also found emodin in the leaves of *C. tora*. Toxicity has been observed in cattle and broilers, and other animals are also susceptible to the toxic effects of this plant.

Singh *et al.* (2001) conducted an experiment on broilers looking at the impact of *C. tora* seed on their growth and meat production. The results indicated that *C. tora* seed can be safely incorporated up to the 10% level in broiler mash. This study confirmed the results found previously by Pandit *et a*l. (1979). These reports indicate that *Cassia* seeds can be incorporated in animal feed, but it would be even better if the entire plant could be utilized as a source of feed.

Previous studies by Gupta *et al*. (1970, as cited by Ranjhan *et al*., 1971) have shown that a neglected summer legume (*C. tora*) that is not accepted in the green stage, when conserved into silage, with or without molasses, was readily accepted by the livestock and showed high nutritive values. Ranjhan *et al*. (1971) reviewed the chemical composition and nutritive value of *C. tora* fed as hay and compared it to the *C. tora* fed as a green plant and/or as silage. The green plant was collected at flowering, air dried for a day, and stored in the shed for a day until the dry matter content of the fodder reached approximately 75%. The hay was evaluated after a month and fed to adult sheep. Palatability was determined using four yearling rams and four three-year old male buffalo calves. Gupta *et al*. (1970) as cited by Ranjhan *et al*. (1971) observed that the fodder was palatable and could be compared to the dry matter consumption observed on feeding *C. tora* silage. The chemical composition and nutritive value of *C. tora* hay was found to contain 12.70, 26.80, 1.76, 47.00, 2.41, and 0.64% of crude protein, crude fiber, ether extract, nitrogen free extract, calcium, and phosphorous, respectively. The digestibility coefficients for organic nutrients in *C. tora* hay were significantly more than the silage Gupta *et al*. (1970) as cited in Ranjhan *et al*. (1971) reported earlier. The data for the chemical composition and digestibility of *C. tora* hay as compared to silage are given in Tables 4.1 and 4.2.

The silage concept is more prevalent in temperate regions, with their distinct seasons, than in the tropics. Nevertheless, silage production in the tropics has become more relevant to fulfill the forage needs of smallholder farmers (FAO, 2000). Silage making is less dependent on weather conditions than haymaking. More research needs to be done to determine the potential of *C. tora* conservation as silage and to evaluate *Cassia* nutrition and toxicity in silage. The overall objective of this experiment was to increase forage resources and provide a source of feed for the dry season. Specific objectives were:

1. To evaluate the chemical characteristics (crude protein, *in vitro* dry matter digestibility, fiber, etc.) of ensiled vs. fresh *C. tora*.
2. To examine the effect of additives (water or honey) and other forages (grasses) on the quality of the ensiled material.

Materials and Methods

Summer 2002

Cassia tora was collected from three locations (Siragourou, Nérékoro, and Madiama villages) within Madiama Commune, Mali (Fig. 4.1). Most of the *C. tora* plants were at an advanced stage of maturity (more stem and fruits than leaves). Prior to ensiling the plant, samples were collected and separated into stem, leaf, and seedpod, and dried to determine the percentage dry weight of each component. Percent stem, leaf, and seedpod were 80%, 19.6%, and 0.4%, respectively. In a 'normal' growing season (in terms of rainfall and temperature), *C. tora* would be at an early to late flowering stage at the end of October. However, during the 2002 growing season only 430 mm of rainfall were recorded in Madiama, 350 mm less than the previous year. Due to the extreme drought conditions, the plants were stimulated to enter the reproductive stage earlier in the season.

Wilting was not necessary before ensiling, because the plants had an adequate dry matter level. Prior to placing the chopped material in the bags that were used as simulated silos, a sub-sample of fresh *C. tora* was taken from each location for dry matter determination and chemical analysis. The moisture content of the ensiled material varied slightly among locations. In general, the moisture content of the fresh chopped plants (no treatment added) was lower for the Siragourou and Nérékoro locations than for those of Madiama. To facilitate chopping for proper cutting length, which was done with a long sharp machete, the plants were placed on a wooden block. In Madiama, local women chopped the plants to a length of 0.5 to 1.5 cm; in the other locations, the villagers participated in the chopping and the length varied between 1 and 3 cm (Fig. 4.2). To enhance the quality of the silage and improve its nutritional value, two additional treatments were incorporated prior to ensiling. The treatments consisted of fresh material only (control), and fresh material with water (1 cup ~ 230 mL) or honey (1 cup ~ 230 mL) added. Since the fresh material was drier than desired for ensiling (over 70% DM), water was added (700 mL bucket^{-1}) to facilitate the ensiling process (fermentation) and improve silage quality.

Chopped samples from each location were placed in a 31 X 51 cm, 4-mil polyethylene bag. Air was excluded from samples in the bag by exerting weight on the plastic bags, and the top of the bags were folded, gathered, and wrapped with masking tape

(Fig. 4.3). All samples were grouped by location and placed in a larger plastic bag to start the fermentation process for either 60 or 90 days. After 60 or 90 days, the ensiled samples were opened and immediately given visual, color and mold ratings, as well as sensory scores for sharpness (acidity) or off odors.

Summer 2003

As in 2002**,** *C. tora* was harvested from the same three locations and processed similarly to the previous year. In 2003 *Cassia* was ensiled as is, with sugar (1 cup ~ 230 mL), or with 20% chopped grasses. The grass components for this location were 40% *Dactyloctenium aegyptium*, 10% *Digitaria longitudinalis*, 20% *Elucine indica*, and 30% *Panicum laetum*. For the Siragourou location, the grass components were 50% *Bracaria* sp, 30% *Elucine indica*, and 20% *Dactyloctenium aegyptium*, while at the Madiama village location, the components were 10% *Elucine*, 10% *Panicum laetum*, 40% *Dactyloctenium aegyptium* and 40*% Digitaria horizontalis*. The chopped materials were packed into small plastic bags for ensiling according to the methodology used at the Nérékoro location. Since no significant difference in silage quality between the 60 and 90-day ensiling period was observed in 2002; in 2003 only a 60-day period was used to ensile the *C. tora.* After 60 days, bags were opened and visually assessed. Sub-samples were obtained from each bag for quality analysis.

Laboratory analysis

Samples in 2002 were dried in a forced-air oven at 60^{o}C, ground (1-mm screen) in a stainless steel Wiley Mill (Thomas-Willey Mill, Model ED-5, Arthur H. Thomas Co., Philadelphia, PA), and analyzed for acid detergent fiber (ADF) (Van Soest, 1963), neutral detergent fiber (NDF) (Van Soest and Wine, 1967; Goering and Van Soest, 1970), *in vitro* dry matter digestibility (IVDMD) (Tilley and Terry, 1963), and crude protein (CP), total N was determined colorimetrically (McKenzie and Wallace, 1954) with a Technicon Autoanalyzer (Technicon Industrial Systems, Tarrytown, NY; 1976). In 2003, samples were analyzed for CP, ADF, and total digestible nutrients (TDN).

Statistical analysis

Three treatments replicated 3 times (control, honey or sugar, and water or grass) were applied at three levels. Level 0 represents the fresh samples (not ensiled), level 60 represents the samples ensiled for 60 days, and level 90 represents the samples ensiled for 90 days (2002). In 2003, level 90 was dropped; instead the effect 'type' (either fresh or ensiled) was tested. A randomized complete block design (RCBD) was used to perform the analysis. Analysis of variance (ANOVA) procedures were performed on all data to test the treatment effects on various measured parameters using the GLM procedure of SAS (SAS Inst., 2001). The treatment means were compared using least significant difference (LSD) at $P = 0.05$.

Results and Discussion

Crude protein (CP)

In 2002, *C. tora* CP varied from 9 to 10%. The addition of honey prior to ensiling showed a trend with a slight increased CP (Fig. 4.4). There was no significant difference between fresh and ensiled samples. The percent CP in the August 2003 fresh and ensiled *C. tora* was up to 50% higher than the October 2002 samples (Fig. 4.5). The average CP in the 2003 *Cassia* samples ranged from 15-22%. This significantly (numerically) higher CP content in the 2003 *C. tora* was due to the fact that the fresh material ensiled in August had a higher leaf to stem ratio (50% stem, 40% leaf, and 10% seedpod) than October 2002 (80% stem, 19% leaf, 1% seedpod) (Table 4.3). Leaves of grasses or legumes have more CP and less fiber compared to the lignified part of the plants. As the plant matures, the CP content declines, while the fiber components of the plant increase proportionally. Treatment by type (fresh or ensiled) interaction had a significant effect on all three treatments, with significant higher values for the fresh type. There were no significant differences in CP among treatments within each type (Fig. 4.5). The CP values reported for 2002 are consistent with the slightly higher values Ranjhan *et al*. (1971) previously reported. Differences in CP between 2002 and 2003 may be attributed to the time the *Cassia* was harvested and the stage of maturity of the plant prior to ensiling.

Neutral detergent fiber and acid detergent fiber (ADF, NDF)

In 2002, the ADF values ranged from 34% to 42% (Fig. 4.6). The combined effect of ensiling and the addition of honey reduced ADF values, a trend also observed by Ranjhan *et al*. (1971). The addition of honey to *C. tora* prior to ensiling decreased ADF values by 8 percentage points (42% for the control vs. 34% for honey treated silage). The ADF values observed for the ensiled *C. tora* are comparable to mature alfalfa hay. Generally, the ADF values of the fresh *C. tora* were lower in 2003 than in 2002, and varied from 30 to 38% (Fig. 4.7). This was not surprising, because the *Cassia* sample in August of 2003 was much higher in leaf (low in ADF) than stem and seedpod content. The percent ADF of the ensiled *C. tora* was significantly higher than the fresh *C. tora* for the control and the grass treatment (Fig. 4.7). The addition of sugar to the ensiled *C. tora* decreased ADF by 3 percentage points (38% for the grass treated vs. 34.6% for the sugar treated silage), but there were no significant differences among treatments within each type (fresh or ensiled). Overall, for both 2002 and 2003, the ADF values of the ensiled *C. tora* were acceptable values to maintain a reasonable animal production level.

Ensiling *C. tora* decreased the amount of NDF compared with the fresh *C. tora* (Fig. 4.8). Within the ensiled Cassia (both at level 60 and 90), treatment had a significant effect, the addition of honey gave the lowest NDF value. Also, across types, the honey treated ensiled *Cassia* was significantly lower than the fresh *Cassia* that had been treated with honey. The percent NDF in the ensiled *Cassia* (ensiled 60 days) was 57%, 50%, and 52% for the control, honey, and water treated *Cassia*, respectively. NDF values of grass or grass legume hay, depending on stage of maturity, range from 40-65%. As the plant matures from vegetative stages to reproductive stages, NDF values increase significantly.

In Vitro dry matter digestibility (IVDMD) and total digestible nutrient (TDN)

When compared to fresh *C. tora*, ensiling increased IVDMD (Fig. 4.9). Averaged over all treatments, IVDMD of the ensiled Cassia was 6 percentage points higher than the fresh *C. tora*. The addition of honey as an additive significantly improved the IVDMD of the ensiled *Cassia*. The IVDMD of the honey treated *C. tora* was 63% compared with 54% for *Cassia tora* ensiled fresh (with no additives). These values are comparable to typical warm and cool-season forage crops grown in temperate regions.

The fresh *Cassia* was significantly higher in TDN than the ensiled *C. tora* for both control and grass treatment (Fig. 4.10). This might have been due the fact that the fresh material was of a higher quality as indicated by its high leaf to stem ratio and some energy was lost during the fermentation process. Within the ensiled *Cassia*, the honey treated *Cassia* was slightly higher in TDN than the control and grass treated *Cassia*, but there were no significant differences among treatments within each type. Although the addition of grass slightly reduced the TDN values of the ensiled *C. tora*, this could be explained by the advanced stage of maturity of the grass added.

Summary

In terms of nutrient values, as indicated by acceptable crude protein, fibers, relatively high *in vitro* dry matter digestibility and total digestible energy values, ensiled *C. tora* has a good deal of potential as a livestock feed. Although the October 2002 ensiled *C. tora* had relatively low nutrient values due to a low leaf to stem ratio of the fresh *C. tora*, it would still make a reasonably good feed for livestock. The addition of honey or sugar, as the results in this study have shown, improves the quality of the ensiled material. Similar studies in Australia and other tropical regions, using molasses or sugar, have reported similar results (Muhlback, 2000). In general, the August 2003 ensiled *C. tora* had substantially higher percent CP and lower fiber. The August 2003 fresh *Cassia* was high in leaf content compared to the October 2002 fresh *C. tora*, indicating that unless the raw material (the fresh sample) is of a reasonable quality (as seen in 2003), the ensiling process per se would not enhance the quality of the end product. However, if the fresh material is excessively dry and low in sugar (case of 2002), the addition of water or a carbohydrate source can enhance the quality of the material by improving the ensiling processes (such as fermentation).

The goal for this project was to help Madiama Commune find a feed source they can tap into during the dry season when livestock feed is in short supply. In a much drier year like 2002, the entire feed source for the livestock was gone at least two months before the end of the ‘normal’ production season, and *C. tora* was the only live and visible plant in the entire Commune. *Cassia tora* even at its late stage of maturity could provide a good feed source with reasonably high nutrient content.

As for the question of toxicity, it is not clear how animals respond to a *cassia* diet as evidenced by the various studies. Although anthraquinones are the major toxic compounds found in *C. tora*, other toxins have been identified as well. However, both Gupta *et al*. (1970) and Ranjhan *et al*., (1971) suggested that livestock readily accepted *C. tora* conserved as hay or silage. Further, toxicity analyses of ensiled *C. tora* are needed before feeding recommendations can be made.

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Table 4.1 Percent (%) chemical composition of Chakunda (*C. tora*) hay as compared to Chakunda silage (Ranjhan et al., 1971).

Treatment	Dry matter	Crude protein	Ether extract	Crude fiber	Nitrogen free extract	Calci-um	Phosph-orus
Chakunda hay	84.50	12.70	1.76	26.80	47.00	2.41	0.64
Chakunda green	20.90	12.92	4.12	24.35	46.44	2.19	0.39
Chakunda silage (without molasses)	23.75	10.51	3.43	30.96	44.05	2.22	0.43
Chakunda silage (with molasses)	28.82	12.72	2.41	23.55	51.22	2.33	0.40

Table 4.2 Digestibility coefficients (%) of various nutrients in Chakunda (Ranjhan et al., 1971).

Treatment	Dry matter	Crude protein	Crude fiber	Ether extract	Nitrogen free extract
hakunda hay	60.66 +/- 1.96	57.09 +/- 3.33	68.52 +/- 2.37	34.83 +/- 1.46	57.00 +/- 3.20
Chakunda silage (without molasses)	59.20 +/- 1.34	39.74 +/- 1.11	49.66 +/- 1.21	15.36 +/- 3.15	71.13 +/- 2.89
Chakunda silage (with molasses)	55.80 +/- 1.01	40.69 +/- 0.86	59.41 +/- 1.96	7.51 +/- 3.50	68.62 +/- 1.82

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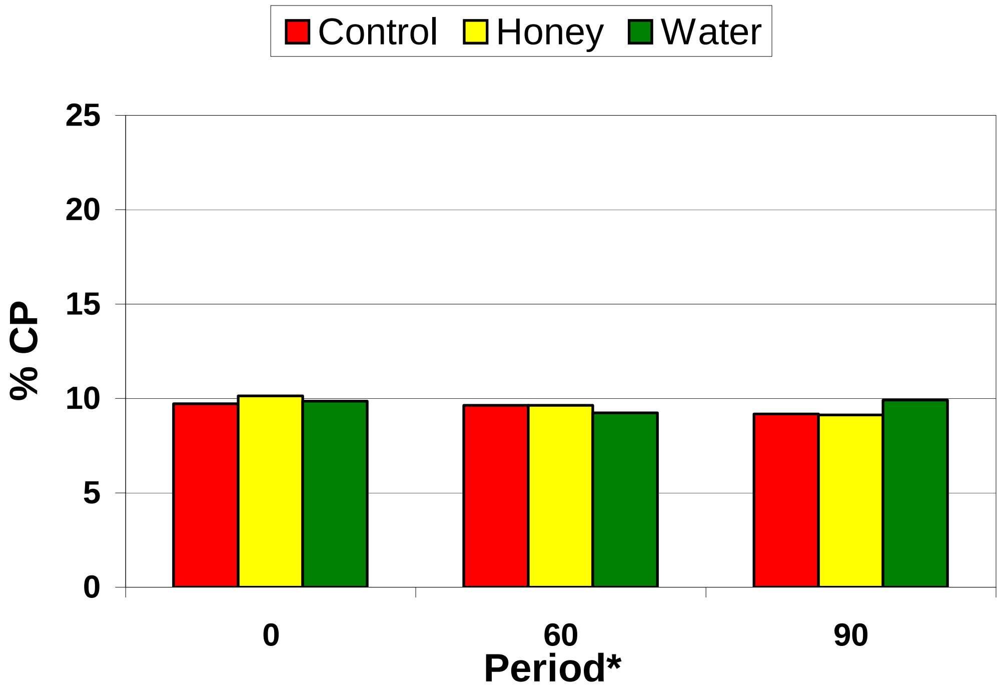
Fig. 4.1 *Cassia tora* observed in the field, Nerekoro location, **Madiama Commune of Mali (West Africa**), October 2002

Fig. 4.2 Women from the village of Nerekoro chopping *Cassia tora* prior to ensiling, **Madiama commune of Mali (West Africa)**, August 2003

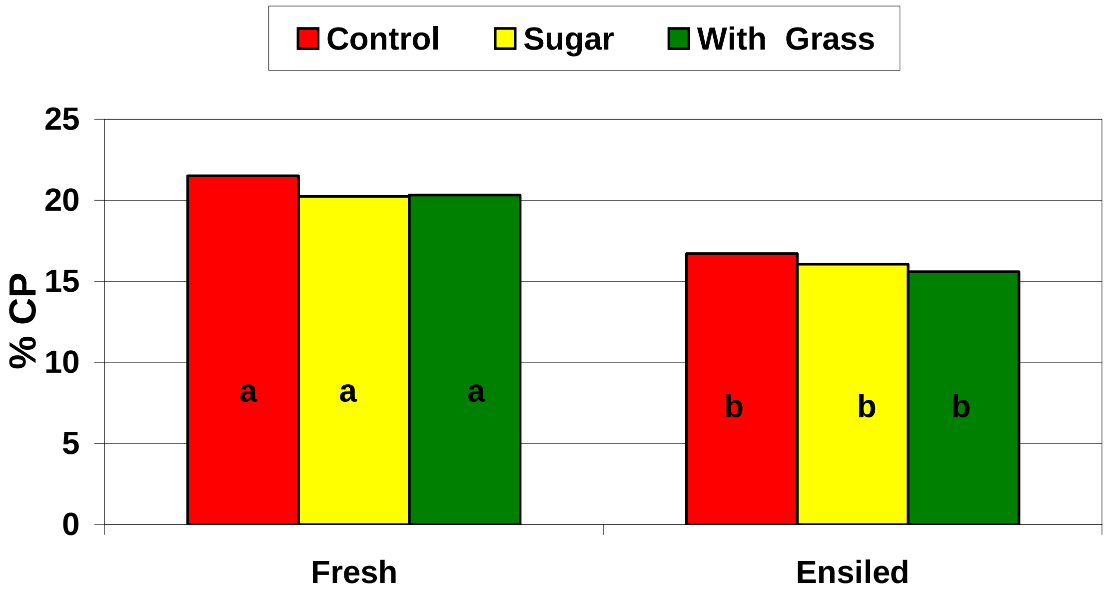
Fig. 4.3 Treated and untreated *Cassia tora* ensiled in a 31 X 51 cm, 4-mil polyethylene bag, **Madiama Commune of Mali (West Africa**), October 2002

Fig. 4.4 Percent crude protein (CP) in fresh vs ensiled *Cassia tora*. Madiama Commune of Mali (West Africa)**, October 2002**



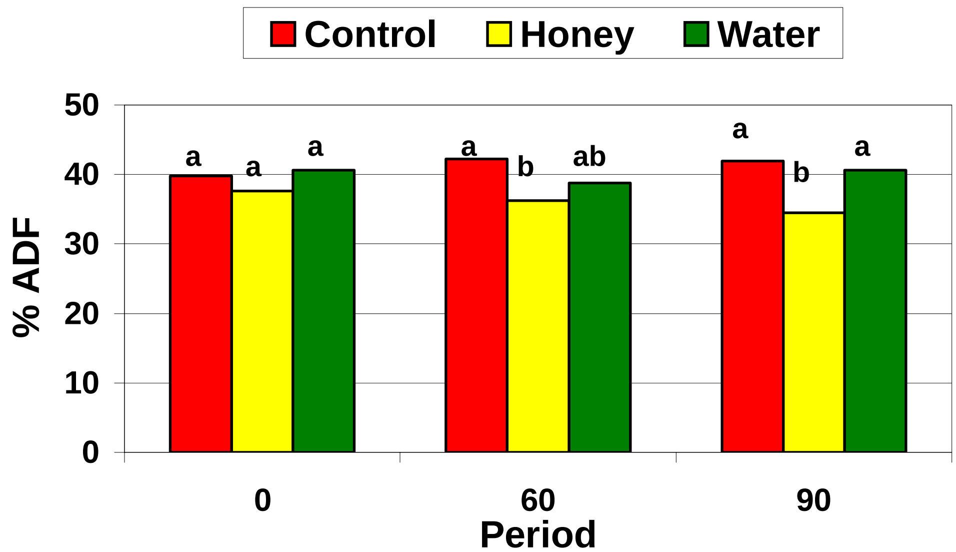
* Period refers to period of fermentation, either ‘0’ for no fermentation (fresh material), ‘60’ for 60-day fermentation period, or ‘90’ for 90-day fermentation. In 2003, the 90-day fermentation period was taken and period was replaced by ‘fresh’ and ‘ensiled’. There were no significant differences within or across periods (P>0.1).

Fig. 4.5 Percent crude protein (CP) in fresh vs ensiled *Cassia tora*, Madiama Commune of Mali (West Africa), **August 2003**



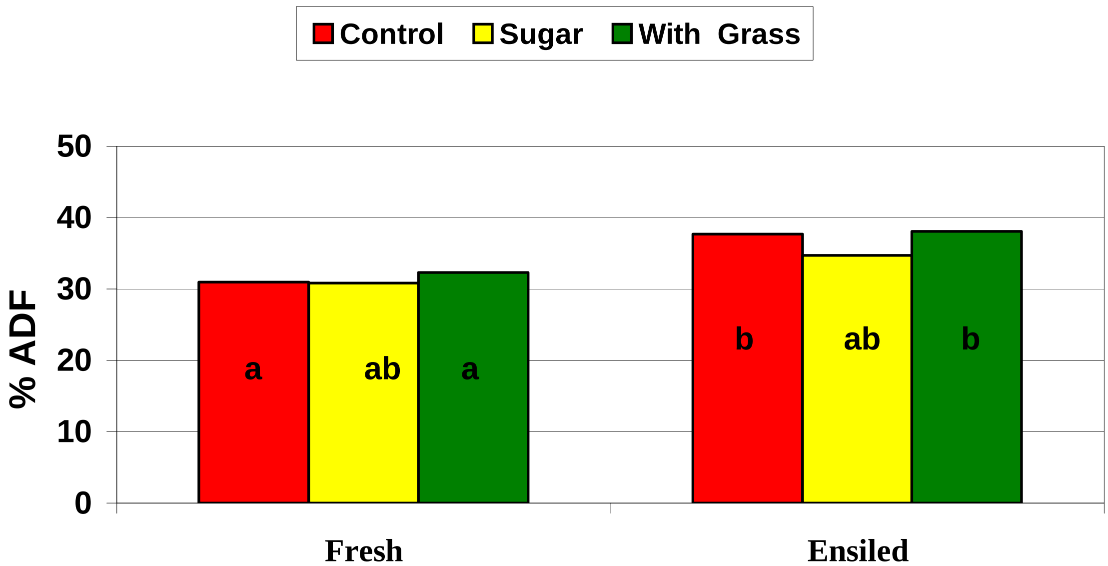
* Same letters are not significantly different (P < 0.05). There were no significant differences among treatments within each type, fresh or ensiled. There was a significant interaction between treatment and type for all treatments, with higher CP for the fresh material.

Fig. 4.6 Percent acid detergent fiber (ADF) in fresh vs ensiled *Cassia tora*, Madiama Commune of Mali (West Africa)**, October 2002**



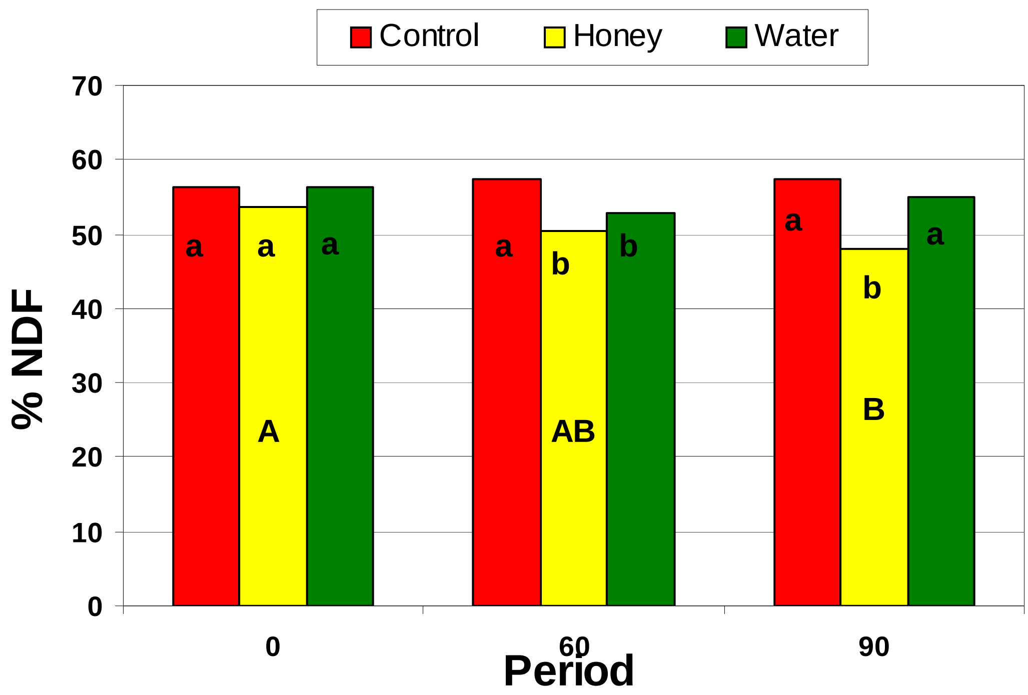
* There was no significant treatment by period interaction effect (P>0.05). Treatment effect was significant for both ensiled material, with significant lower ADF for the honey treatment.

Fig. 4.7 Percent acid detergent fiber (ADF) in fresh vs ensiled *Cassia tora,* Madiama Commune of Mali (West Africa) **August 2003**



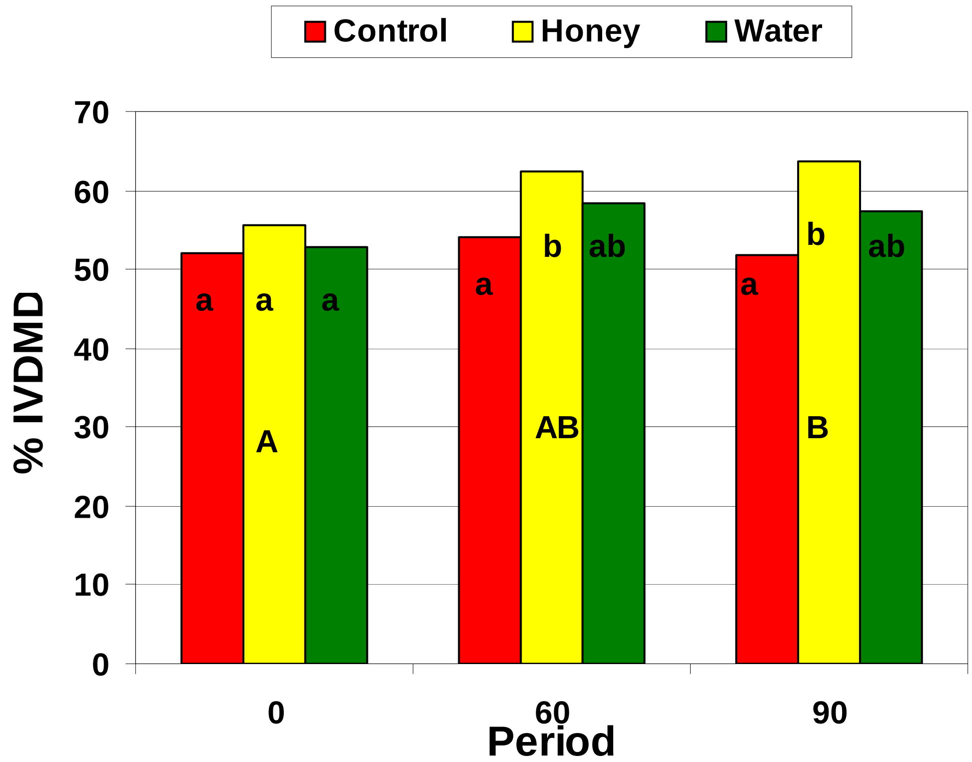
* There were no significant differences among treatments within both ‘fresh’ and ‘ensiled’ material (P>0.05). There was a significant treatment by type interaction for the control and the grass treatments (P<0.05).

Fig. 4.8 Percent Neutral detergent fiber (NDF) in fresh vs ensiled *Cassia tora*, Madiama Commune of Mali (West Africa), **October 2002**



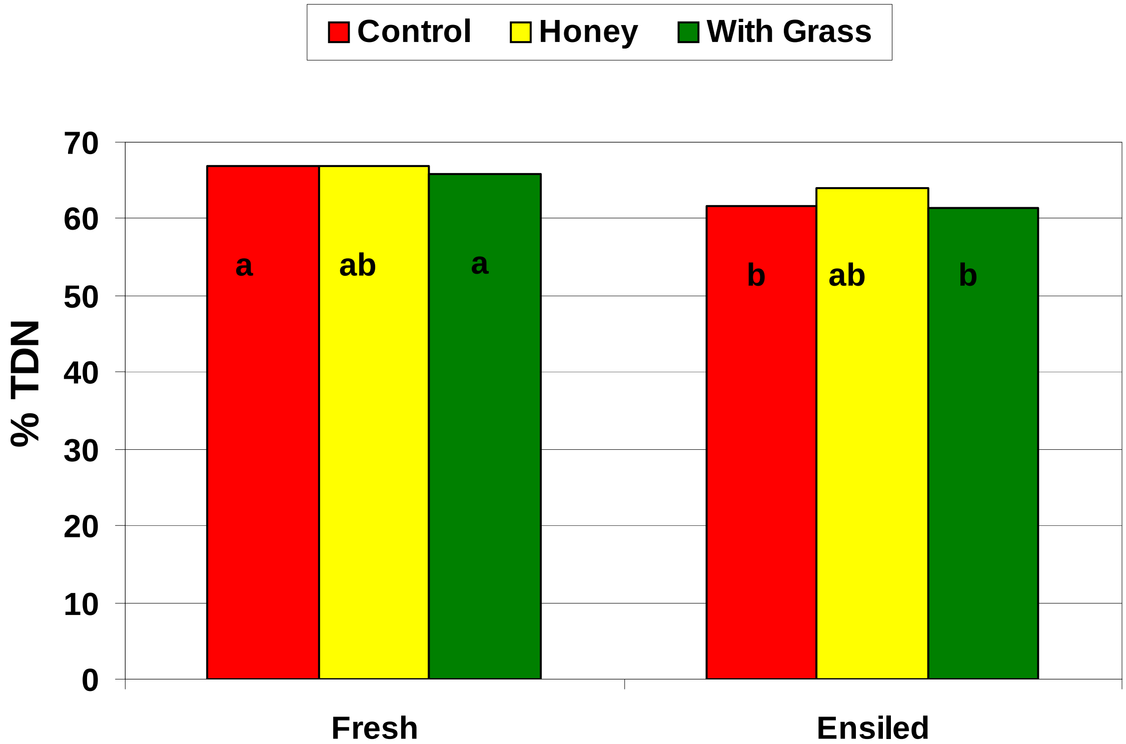
* There was a significant treatment by period interaction for the honey treated material (P<0.05). Treatment effect within each period was significant for the ensiled material, with lower values for the honey treatment (P<0.05).

Fig. 4.9 Percent Invitro dry matter digestibility (IVDMD) in fresh vs ensiled *Cassia tora*, Madiama Commune of Mali (West Africa), **October 2002**



* There was a significant treatment by period interaction for the honey treated material (P<0.05). Treatment effect within each period was significant for the ensiled material, with higher values for the honey and water treatments (P<0.05).

Fig. 4.10 Percent total digestible nutrients (TDN) in fresh vs ensiled *Cassia tora*, Madiama Commune of Mali (West Africa), **August 2003**



* There were no significant differences among treatments within both 'fresh' and 'ensiled' material (P>0.05). There was a significant treatment by type interaction for the control and the grass treatments (P<0.05).

Chapter V

Influence of phosphorus sources and rates on uptake by Cassia tora L.

Abstract

Low soil fertility, particularly P deficiency, is one of the major constraints affecting African agriculture. Indigenous tropical plants can improve soil fertility through various mechanisms. The ability of some plants to extract soil P forms normally unavailable to other crops has been under study recently. A greenhouse study was conducted to evaluate the effects of various P sources and rates on *Cassia tora* L. growth and to examine the possibilities of differential utilization of various P sources by *C. tora*. Phosphorous sources included Tilemsi PR from Mali (TPR), North Carolina PR (NPR), aluminium phosphate (AlP), iron phosphate (FeP), and triple superphosphate (TSP). TSP was used as a reference fertilizer, and a control with no fertilizer added was included. Fertilizers were applied to an acidic (pH=5.8) Shottower (loamy sand) soil at rates of 0, 20, 40, 60, and 80 (TSP only) mg P kg^{-1} soil. *Cassia tora* was grown for 11 weeks. Tilemsi PR and NPR were 81 and 87.5% as effective as TSP, respectively, in increasing *C. tora* dry-matter yields. The control, FeP, and AlP were 30, 50, and 77.7% as effective as TSP, respectively, in increasing *C. tora* dry-matter yields. The same trends were obtained when P uptake was used to compare effectiveness. These results showed that *C. tora* can produce acceptable levels of dry matter at low level of soluble soil P. The plant was also shown to produce more (than the low level and the control treatments) dry matter in response to higher levels of available P. Water extractable P was found to be more accurate in estimating available soil P compared with the Mehlich 1 extract. Mehlich 1 overestimated available P in soil treated with both PRs.

Introduction

Africa south of the Sahara is the only remaining region of the world where per capita food production has remained stagnant or declined over the past 40 years. Approximately 180 million Africans do not have access to sufficient food to lead healthy and productive lives, making them more susceptible to the ravages of malaria, HIV-AIDS, and tuberculosis (Sanchez, 2002). Low soil fertility, particularly N and P deficiencies, is one of the major biophysical constraints affecting African agriculture (FAO, 1971; DeWit, 1981; Penning de Vries & Djiteye, 1982; Mokwunye et al., 1996). Until very recently, the focus has been primarily on other biophysical limitations such as soil erosion, drought, and the need for improved crop germplasm

(Sanchez et al., 1997). Sanchez et al. (1997) explains that no matter how effectively other conditions are improved, per capita food production in Africa will continue to decrease unless soil fertility depletion is effectively addressed. Sanchez et al. (1997) describe the magnitude of nutrient depletion in sub-Sahara Africa as enormous: an average of 660 kg N ha^{-1}, 75 kg P ha^{-1}, and 450 kg K ha^{-1} has been lost during the last 30 yrs from about 200 million ha of cultivated land in 37 countries. This is equivalent to 1.4 t urea ha^{-1}, 375 kg triple superphosphate (TSP) ha^{-1}or 0.9 t PR of average composition ha^{-1}, and 896 kg KCl ha^{-1} during the last three decades. These figures represent the balance between nutrient inputs (fertilizer, manure, atmospheric deposition, biological N_2 fixation, and sedimentation), and nutrient outputs (harvested products, crop residue removals, leaching, gaseous losses, surface runoff, and erosion). According to FAO (1995), sub-Sahara Africa is losing 4.4 million t N, 0.5 million t P, and 3 million t K every year from cultivated land, these rates being several times higher than its annual fertilizer consumption. The vast majority of farmers lack the means to buy fertilizers. Consequently, farming has become soil mining, which is defined as the removal each year of more nutrients than are being added (Van der Pol, 1992).

The majority of the soils found in the Sahel are sandy with an eolian origin (wind erosion); the sandy soil regions are separated by numerous loamy-clay depressions (Penning de Vries and Djiteye, 1991). Low P availability in tropical acid soils often rises from fixation of P by Al and Fe in soil. Generally, Al and Fe-phosphates are relatively unavailable to plants; however, some legumes are able to absorb soil P forms considered to be unavailable (Ae et al., 1990). Identifying such legumes would be useful for maintaining productivity without further addition of fertilizer P and N (Sanchez and Salinas, 1981). Ae et al. (1990) investigated the ability of *Cajanus cajan* (L.) Millsp. (pigeon pea) to extract soil P normally unavailable to other crop plants. The investigators found that Pigeon pea exhibited much greater dry matter production and P uptake on an Alfisol without any fertilizer P than on a Vertisol. They concluded that the better growth of pigeon pea on the Alfisol was related to its ability to utilize Fe-P, which was the dominant form of P in the Alfisol. It was also suggested in this study that root distribution and vesicular arbuscular mycorrhizal (VAM) were not the reason for the differences between pigeon pea and the other crops tested and that more research is needed to look at root exudates and the ability of some compounds to chelate $Fe^{3}+$ from $FePO_4$. Pisidic acid (p-hydroxybenzyl tartaric acid) was one of the organic acids analyzed in this study. Pigeon pea and *Cicer arietinum* L. (chickpea) have been identified to usually grow well in low soil P environments. In a study by Itoh (1987), pigeon pea and chickpea were found to be able to take up more P at lower concentrations of P as compared to *Glycine max* (soybean) and *Zea mays* (maize) that responded better to higher P applications. In a more recent study by Zoysa et al. (1999) in the tropics, P utilization efficiency and depletion of phosphate fractions in the rhizosphere of three *Camellia thea* L. (tea) clones were observed. All three tea clones induced acidification of the rhisosphere and researchers attributed higher P uptake efficiency of two clones to their higher root acidification, root exudation of organic compounds, and/or mycorrhizal association. Ascencio (1996) studied the effects of P deficiency on the physiology of two tropical leguminous species. The author suggested that enzyme activity, total leaf area, and relative growth rate (during exponential growth phase) were appropriate physiological indicators for the differentiation of *Desmodium* plants grown under P deficiency or sufficiency. The results indicated that the activity of acid phosphatase secreted by the roots increased under P deficiency in both species.

Sanchez and Salinas (1981) examined the effectiveness of various phosphate rocks as compared to that of triple superphosphate, using *Panicum maximum* as the test crop on an Oxisol from the Llanos Orientakes of Colombia. Three phosphate rocks were tested; a high-reactivity phosphate rock from North Carolina, a medium-reactivity rock from Florida, and a low-reactivity rock from Brazil, Colombia, and Venezuela. Phosphate rocks performed nearly as well as the triple superphosphate and in some instances outperformed the triple superphosphate in the long run. Mali's major mineral resources include phosphate rock. Tilemsi phosphate rock (Tilemsi PR) in Mali has been tested as direct application phosphate fertilizer in various experiments (Diamond et al., 1989; Chien and Menon, 1995). The results from these experiments showed that the relative agronomic effectiveness (RAE) of directly applied ground Tilemsi PR was close to that of triple superphosphate (TSP). Bationo et al. (1997) findings are in agreements with Diamond et al. (1989) and Chien and Menon (1995) reporting that direct applications of Tilemsi PR resulted in yields comparable to those of recommended imported fertilizers for *Gossypium* (cotton) or cereal crops. Hoffland (1991) studied the uptake of sparingly soluble rock phosphate by rape (*Brassica napus*). It was found that phosphate-deficient rape plants are able to mobilize rock phosphate by exuding organic acids, malic and citric acids in particular, causing the acidification of the rhizosphere.

Hoveland et al. (1976) found that *Cassia occidentalis* L. and *Cassia obtusifolia* L. (sicklepod) to be the most tolerant of low available soil P. Mappaona and Yoshida (1995) studied the growth and nitrogen fixation of three leguminous plants under various forms of P applications; *C. tora* was identified as a non-nodulated legume and was found to have an intermediate response to P fertilization. *Cassia* is found throughout the tropics and grows abundantly in our experimental sites in Mali under very low P and degraded soil conditions. Quantitative information on *Cassia*'s ability to cope with low P environments is unavailable.

A greenhouse study was conducted to determine the effects of various P sources and rates on *C. tora* growth and to examine the possibilities of differential utilization of various P sources by *C. tora.*

Materials and methods

Soil

A greenhouse study was conducted in 2004 using different sources and rates of P to examine P uptake and growth of *C. tora*. Soil for the greenhouse study was collected from the sub-surface 18-36 cm layer of a loamy sand acidic Shottower (Typic Paleudults) at Kentland farm, Blacksburg, Virginia. This soil was chosen because of its similar physical and chemical properties to the soil found in our experimental site in Mali. After collection, the soil was air-dried, sieved through a 5 mm sieve to remove roots and stones. For chemical analysis, a subsample of the air-dried soil was ground to pass 2mm sieve. The sample was subsequently analyzed for pH (1:1, soil/water), extractable bases, and micro-nutrients following procedures used by the Virginia Tech Soil Testing Laboratory. Mehlich I (0.05M HCl and 0.0125 H_2SO_4) (Mehlich, 1953) extractable P was 2 mg kg^{-1} soil which corresponded to a rating of "very low" for P (Cope *et al*., 1981 as cited by Mullins and Sikora, 1995; Donohue and Heckendorn, 1994). Soil pH was 5.8; Mehlich 1 extractable K, Ca, and Mg were 34, 165, and 46 mg kg^{-1}, respectively. Zinc, Mn, Cu, Fe, and B were 0.9, 7.6, 0.2, 17.1, and 0.1 mg kg^{-1}, respectively.

Soil moisture was maintained above 50% field capacity by daily additions of water. To determine field capacity, pots were set up with the soil, oversaturated with tap water, and allowed to drain for 48 hr. Tensiometer readings and soil samples were taken at field capacity and at the wilting point to create a soil moisture characteristic curve. Tensiometer readings were taken on daily basis to ensure that soil water content was above 50% field capacity.

Fertilizers

Five sources of P fertilizers were used in this experiment. Finely ground Tilemsi Valley/Mali PR (28.6% P_2O_5) and North Carolina/USA PR (29.9% P_2O_5) were purchased from the Intenational Center for Soil Fertility and Agricultural Development (IFDC). Mali hosts voluminous high grade Tertiary sedimentary phosphates; the best known phosphate deposits, of Eocene age occur in the Tilemsi River Valley (IFDC, 1977). Truong and Montagne (1998) reported that the surface area of Tilemsi PR is the highest of the PRs of West Africa. The P uptake rate from applied Tilemsi PR and the agronomic effectiveness is correspondingly very high (Truong and Montagne, 1998). North Carolina PR is a high-reactivity (Sanchez and Salinas, 1981) PR and was included to compare with the Tilemsi PR. Triple superphosphate (TSP) was used as a reference fertilizer. The TSP was a granular commercial product. Iron phosphate ($FePO_4$) and Aluminum phosphate ($AlPO_4$) in powder form were purchased from Alfa Aesar, a certified company for fine chemicals for research and development. The hypothesis for using Fe-P and Al-P as P sources was to determine if *C. tora* was able to utilize these insoluble P fertilizer sources.

Greenhouse

Seeds from *C. tora* were collected from plants growing wild in Madiama, Mali in fall of 2003. Three and a half kg subsample of the Shottower soil were weighed into plastic lined pots. The 5 phosphate fertilizer materials were added at rates of 0 (control), 20, 40, 60, and 80 (for TSP only) mg total P kg^{-1} soil and thoroughly mixed. Four *C. tora* seeds were planted pot^{-1}

initially, and 4 more were added after 48 hours to insure that an adequate number of seeds were germinated. Four seedlings emerged in less than 48 hours, 48 emerged after 5 days, but some never emerged. *Cassia tora* produces heterogeneous seeds that can extend the germination process over several weeks (Hien, 1997). After 5 weeks, pots were thinned to 2 plants (3 replicates), and 16 pots had one plant and 2 had no plants (4 replicates). The replicates with 1 plant had a more vigorous growth than the ones with 2 (Fig 5.1). The replicates with 1 plant occurred in all 5 P fertilizer treatments; therefore analyses were done on all 4 replicates of each treatment. At week 3, plants were fertilized with potash (0-60-0) and sprayed with Captain for *Fusarium*, sp. Chakravarti and Mishra (1986) reported that *Fusarium oxysporum* reduced seedling growth of *C. tora* to a great extent. A bird net was placed to protect *C. tora* seedlings (small birds penetrated the greenhouse and had eaten some of the plant seedlings). At week 5, plants were sprayed with Neem oil for aphids; the plants looked stressed but recovered after one week (Fig. 5.2).

Sampling and sample preparation

Cassia tora samples were harvested in October, 2004 (approximately 11 weeks after planting). Shoots and roots were separated by cutting the plant at the soil surface. Both shoot and roots were washed with tap water (roots were washed over a 10-mesh screen), rinsed under de-ionized water to ensure that all the soil was removed, and dried in a forced air oven at 70^{o}C for 48 hrs. Air dried samples were ground in a stainless steel Wiley mill to pass a 0.5mm sieve in preparation for chemical analysis.

Plant analysis

Plant tissue was analyzed for total Kjeldahl P (EPA 351.2 and EPA 365.4; USEPA, 1979), using a block digestion method. Plant tissue (0.2g sample^{-1}) was digested in 3.5 mL of concentrated sulfuric acid (H_2SO_4) in a bloc digester. Three Hengar (Alundum) granules were added in each tube to enhance boiling. Temperature was allowed to ramp to 390°C during the first 2 hours and was held during the third hour. After removing the tubes from the bloc and allowing 10 minutes of cooling, 46.5 mL of DI water was added to each tube, and mixed using a vortex. The final volume was 50 mL. Reagent blanks and standard samples were routinely included in the analysis. Samples were analyzed for total P using a Thermo (Fitchburg, MA) Jarrel Ash ICAP (Inductively Coupled Argon Plasma-Atomic Emission Simultaneous spectrometer, ICP-AES). The percent phosphorus in the solid was calculated by the formula:

% P = [(Vd/Ws) x Cd]/10,000

Where:

Vd = Total digest volume (mL), Default = 50 mL

Ws = Weight of sample (g), Default = 0.2g (plant), 0.4g (soil)

Cd = Concentration in the digest (mg P L^{-1})

Soil analysis

Soil samples were extracted by the Kjeldahl block digestion method (as described above) and analyzed for total P. Mehlich I (0.05M HCl and 0.0125 H_2SO_4) (Mehlich, 1953) and Water-soluble P (1:2 soil to solution ratio shaken for 1hr) (WSP; Self-Davis and Moore, 2000) were employed to extract soluble P.

Statistical analysis

Two separate analyzes were performed on all the data. A completely randomized design (CRD) with a 5 x 3 factorial treatment structure was used to test the linear and quadratic response for the treatment effects on various measured parameters using the Mixed procedure of SAS (SAS Inst., 2001). Multiple comparisons were performed on the treatment least squares means using the Tukey-Kramer test with least significant difference (LSD) at P = 0.05. This analysis did not account for the no-P control and 80 mg P kg^{-1} for TSP, in order to test the factorial effect. A CRD with a one-way ANOVA was used to test 17 treatments (including no-P control and 80 mg P kg^{-1} for TSP) and a T-test with contrasts was used to separate significant means at P = 0.01. The Mixed procedure was also used for the second analysis. Relationships between plant dry matter yield and P uptake, Mehlich 1, and water extractable P were determined by Pearson correlation coefficients.

Results and Discussion

Plant characteristics

Dry Matter Yield

The analyses for plant shoot dry matter yield showed a significant effect for P source ($P<0.0001$), P level ($P=0.0012$), and P source x P level ($P=0.0004$). The yield response was linear for TSP ($P<0.0001$). The response curve shows that P was limiting up to 60 mg kg^{-1} amended P and followed up by a leveling at the higher P rate (Fig 5.3). The overall quadratic effect was not significant ($P=0.2177$). The average dry matter yield across P levels showed no significant difference in yield among all P sources, except for Fe-P. The interaction between P level and source showed that when applied at 40 mg kg^{-1} TSP starts diverging from other treatments, with the exception of NPR (Fig. 5.4). At 60 mg kg^{-1}, TPR yield was comparable to that of TSP (Fig 5.5). At low levels of application; TSP did not improve the dry matter yield as compared to the control (Fig. 5.6). Fig. 5.7 shows dry matter yield of *Cassia tora*, averaged over all treatments. These results indicate that as the level of TSP increases, dry matter will continue to increase up to a certain point. The same trend was not always the case for the other P sources, and this could be explained by the higher solubility of TSP. Although a linear response curve was only significant for TSP; the comparable yield from the PRs indicates that given enough PR to reach the optimum concentration of 60 mg kg^{-1}, we should see a similar response curve for both PRs.

Root weight averaged between 36 and 41% of the total plant weight and root to shoot ratio was not different among P sources except for Fe-P (Fig 5.8). The average (across P levels) dry matter yield of the root was similar for P sources, except for the Fe-P treatment, which was not different from the control (Fig. 5.9).

P Uptake

The analyses for P uptake (mg pot^{-1}) by *C. tora* shoots showed a significant effect of P sources ($P<0.0001$), P level ($P=0.0005$), and P source x P level ($P=0.0079$). The P uptake was linear for TSP ($P<0.0001$) similar to the dry matter yield results (Fig 5.10).The P uptake response curve for TSP was similar to the one observed for yield; as P rate increased, the plant uptake of P increased linearly and leveled off at 60 mg kg^{-1}. Concentrations of phosphorus (mg kg^{-1}) within the plant did not vary significantly among P sources and levels, indicating a typical ‘dilution effect’ of P consumption. The analyses for P concentration in the *C. tora* shoots showed no significant effect for P source

(P=0.2103), a slight effect for P level (P=0.0845), and no significant effect for P source x P level (P=0.1040). The slight effect seen for the effect of P level may be due to an outlier for TPR40 (TPR applied at 40 mg kg^{-1} soil). The relationship between P concentration in the harvested *C. tora* tissue and P level for all sources is shown in Fig. 5.11.

The results for the analyses of P uptake at various P levels are shown in Figs. 5.12, 5.13 & 5.14. The analyses give similar results to the ones obtained for yield; when treatments were applied at a rate of 20 mg P kg^{-1} soil, the difference in plant uptake of P among treatments was not as dramatic as when applied at 40 and 60 mg P kg^{-1} soil. These results indicate again that TSP amended soil was most effective for P uptake at a rate of 60 mg kg^{-1}.

Soil characteristics

Mehlich1

Initially, the unamended soil had a very low extractable P level (2 mg kg^{-1} mehlich 1 P). After addition of the various treatments, the analysis indicated a significant effect for P source, P levels, and P source x P level (P<0.0001). The P response was linear for the Fe-P, Al-P, and TSP treatments (P<0.0001) (Fig. 5.15). The overall quadratic effect for all treatments was not significant (P=0.7895). The two insoluble compounds, iron and aluminum oxide were not different from that of the control. Across all levels of P applications, Tilemsi PR (TPR) had a significantly higher value than North Carolina PR (NPR), and Triple superphosphate (TPS) (Fig. 5.16). Butegwa *et al.* (1996) reported that more P was extracted by Mehlich 1 from soil amended with the unreactive

Sukulu Hills concentrate PR than from TSP. Another study by Butegwa *et al.* (1996) reported that Mehlich 1 consistently overestimated plant available P for PR concentrates. This may be explained by the dissolution of P in the rock, which would not be otherwise available in the soil, by the Mehlich 1 acid extractants. Our findings indicated that for both PRs, Mehlich 1 may have overestimated plant available P.

Water Extractable P

The analyses for water extractable P (H_2OP) showed a significant effect of P sources ($P < 0.0001$), P levels ($P=0.0003$), and P source x P level ($P=0.0058$). The extractable P response was linear for the Fe-P ($P=0.0330$) and TSP ($P<0.0001$) treatments. The overall quadratic effect for all treatments was not significant ($P=0.3031$). When treatments were applied at 20 mg P kg^{-1}, there were no significant differences among all P sources ($P>0.1$). Triple superphosphate, when applied at 40 mg P kg^{-1} had a significantly higher extractable P than all other P sources ($P=0.0489$). Both TSP ($P<0.0001$) and NPR ($P=0.0495$) had significantly higher extractable P than the other P sources, with the highest value for TSP (Fig. 5.17). Averaged across P levels, the TSP treatment had the hightest extractable P levels followed by the PRs treatments (Fig. 5.18). These results are in agreement with Truong and Montagne (1998) findings, indicating that Tilemsi PR from Mali has a reactivity level comparable to that of TSP.

Correlation coefficients (r) between dry-matter yield, P uptake and P extracted by Mehlich1, and water are summarized in Table 5.1. The data shows that Mehlich 1 had a lower overall correlation when all P sources were considered. The relationship between dry-matter yield and extractable P, P uptake and extractable P for various P sources as measured by Mehlich 1 and Water Extractable P methods are shown in Figs. 5.19 and 5.20. These results indicate that water extractable P is a better method for measuring available P and estimating expected P uptake and dry matter yield of *C. tora*.

Summary

Results from this study showed the response of Cassia *tora* to the rate and source of P fertilization. *Cassia tora* grew well and showed efficient P utilization under limited P soil environment. As indicated by both its reactivity (solubility), and use by the plant, Tilemsi PR was as efficient as North Carolina PR. Furthermore, both phosphate rocks could be used as substitutes for TSP. Tilemsi PR and NPR were 81 and 87.5% as effective as TSP, respectively, in increasing *C. tora* dry-matter yields. Similar results by Diamond *et al.* (1989) were reported, with a score of 78% for Tilemsi PR as effective in increasing crop yields as TSP. The ability of *Cassia tora* to solubilize fixed P from Fe- and Al- oxides needs further investigation; the Al-P treatments produced comparable yields to those produced by both PRs and TSP. The results also show that Mehlich 1 would not be a suitable test procedure for evaluating the agronomic performance of either TPR or NPR. On the other hand, water extractable P showed a strong correlation with dry matter yield and P uptake, and seems to be suitable for measuring available P and estimating expected yields on soils treated with plant responsive Tilemsi PR and North Carolina PR.

Various strategies are used for the uptake and acquisition as well as conservation of P within the plant (Lajtha and Harrison, 1995). Some of these strategies include increased root surface area, mycorrhizal interaction, rate of root uptake, and root exudation to aid solubilization of P. The results of our greenhouse study further acknowledged the effects of varied P sources and rates on the growth and utilization of P by *C. tora.* However, further research is needed in the field to account for biological factors, such as mycorrhizal activity, root architecture and rooting depth, which are limited when the plant is grown in a pot.

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Table 5.1 Correlation coefficient (r) between dry-matter yields, P uptake of *Cassia tora*, and P extracted by Mehlich 1 and Water

	Dry Matter Yield	P uptake
Mehlich 1	0.38	0.33
Water	0.59	0.44

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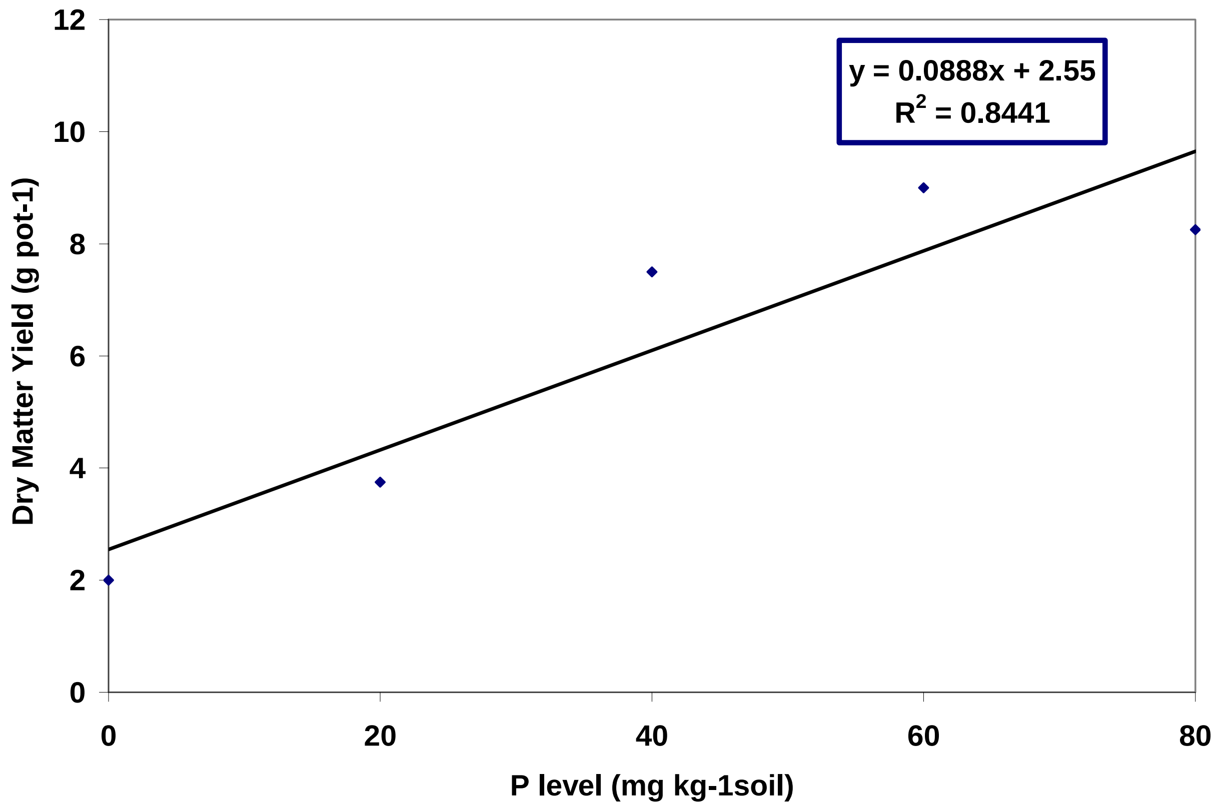

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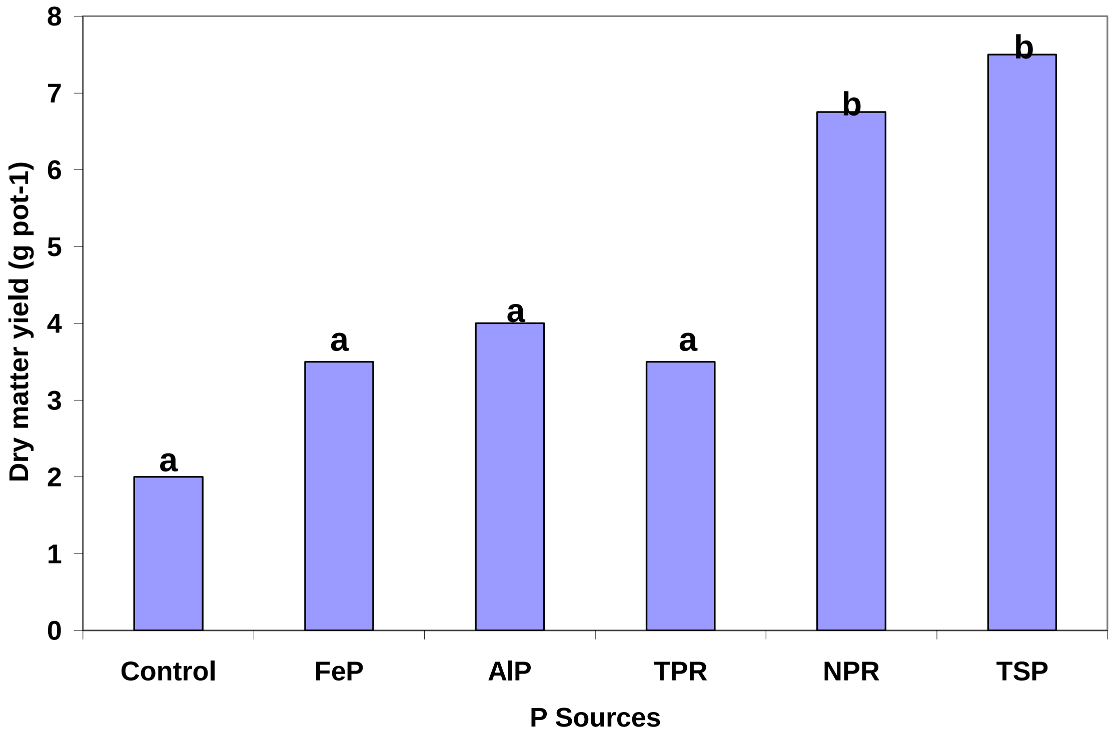
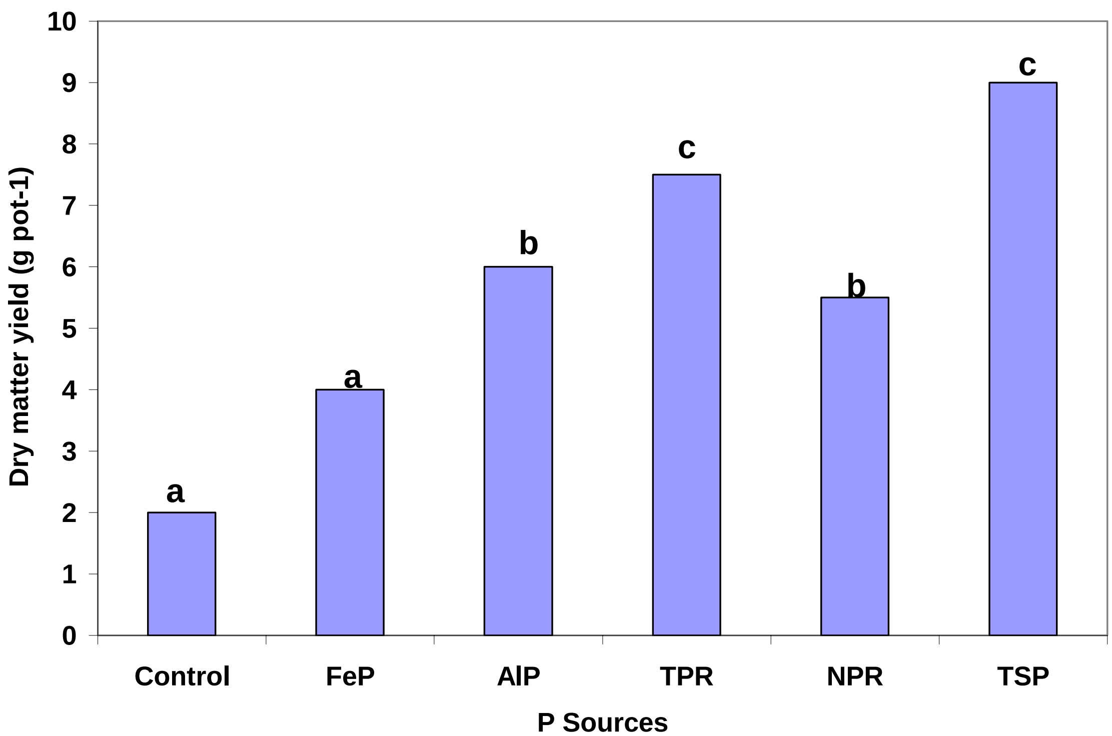


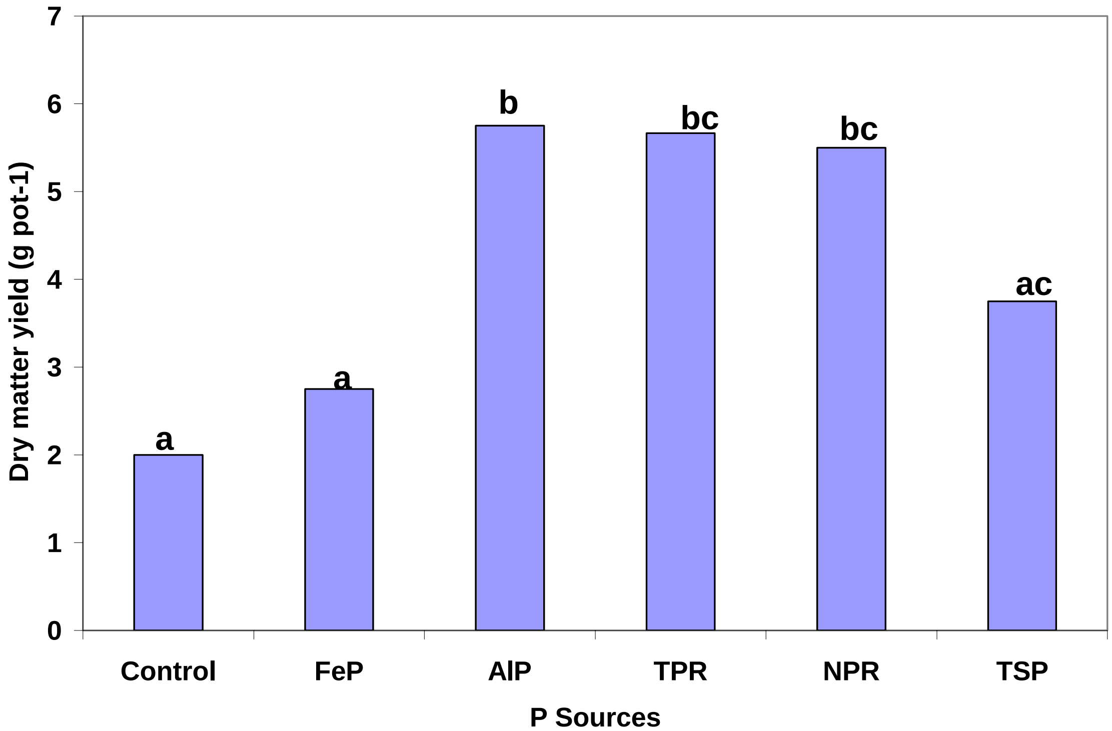
*** Iron phosphate (Fe-P)**
Aluminum phosphate (Al-P)
Tilemsi phosphate rock (TPR)
North Carolina phosphate rock (NPR)
Triple superphosphate (TSP)

Fig. 5.5 Effects of sources of os soil applied P at a rate of 60 mg kg^{-1} on *Cassia tora* dry matter yield, greenhouse 2004



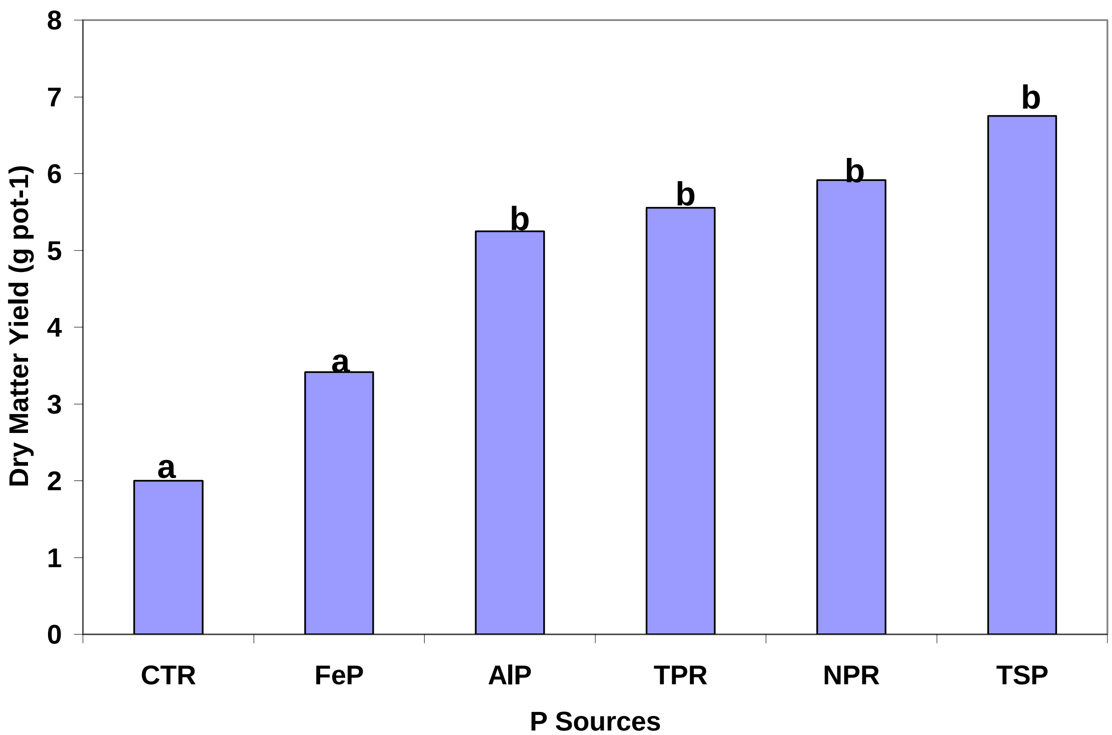
***Iron phosphate (Fe-P)**
Aluminum phosphate (Al-P)
Tilemsi phosphate rock (TPR)
North Carolina phosphate rock (NPR)
Triple superphosphate (TSP)

Fig. 5.6 Effects of sources of soil applied P at a rate of 20 mg kg^{-1} on *Cassia tora* dry matter yield, greenhouse 2004



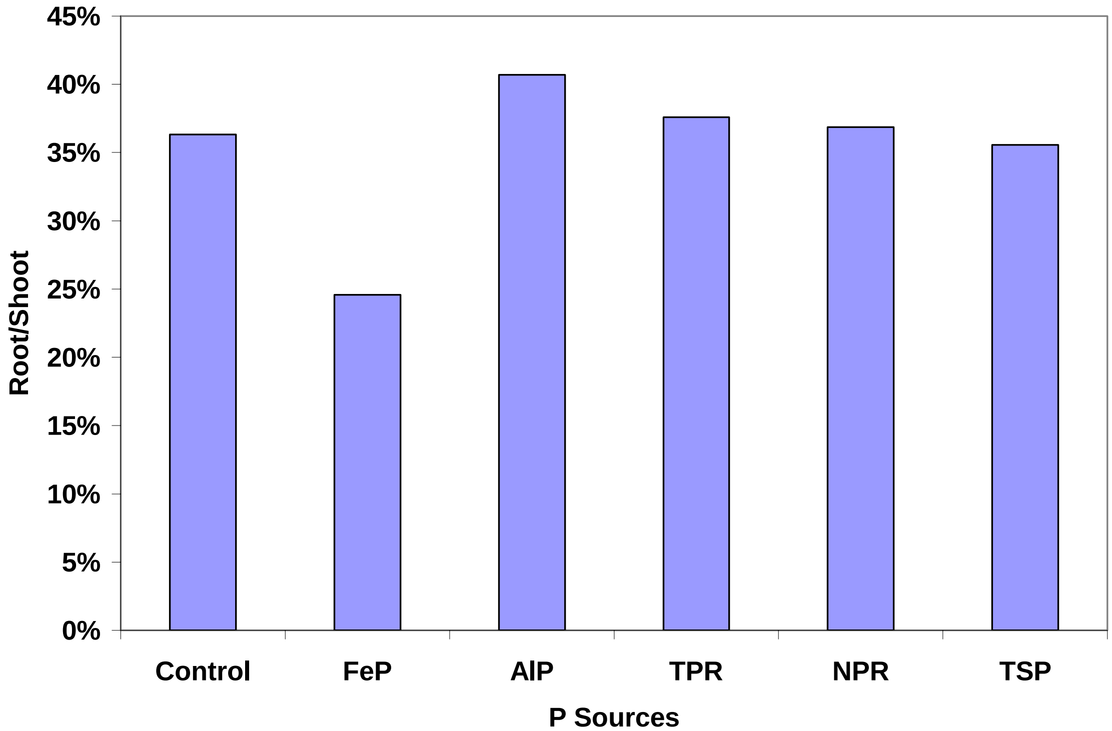
***Iron phosphate (Fe-P)**
Aluminum phosphate (Al-P)
Tilemsi phosphate rock (TPR)
North Carolina phosphate rock (NPR)
Triple superphosphate (TSP)

Fig. 5.7 Effect of soil applied P on dry matter yield of *Cassia tora*, averaged over all P levels, greenhouse 2004



***Iron phosphate (Fe-P)**
Aluminum phosphate (Al-P)
Tilemsi phosphate rock (TPR)
North Carolina phosphate rock (NPR)
Triple superphosphate (TSP)

Figure 5.8 Effect of soil applied P on root to shoot ratios of *Cassia tora*, averaged over all P levels**,** greenhouse 2004



***Iron phosphate (Fe-P)**
Aluminum phosphate (Al-P)
Tilemsi phosphate rock (TPR)
North Carolina phosphate rock (NPR)
Triple superphosphate (TSP)

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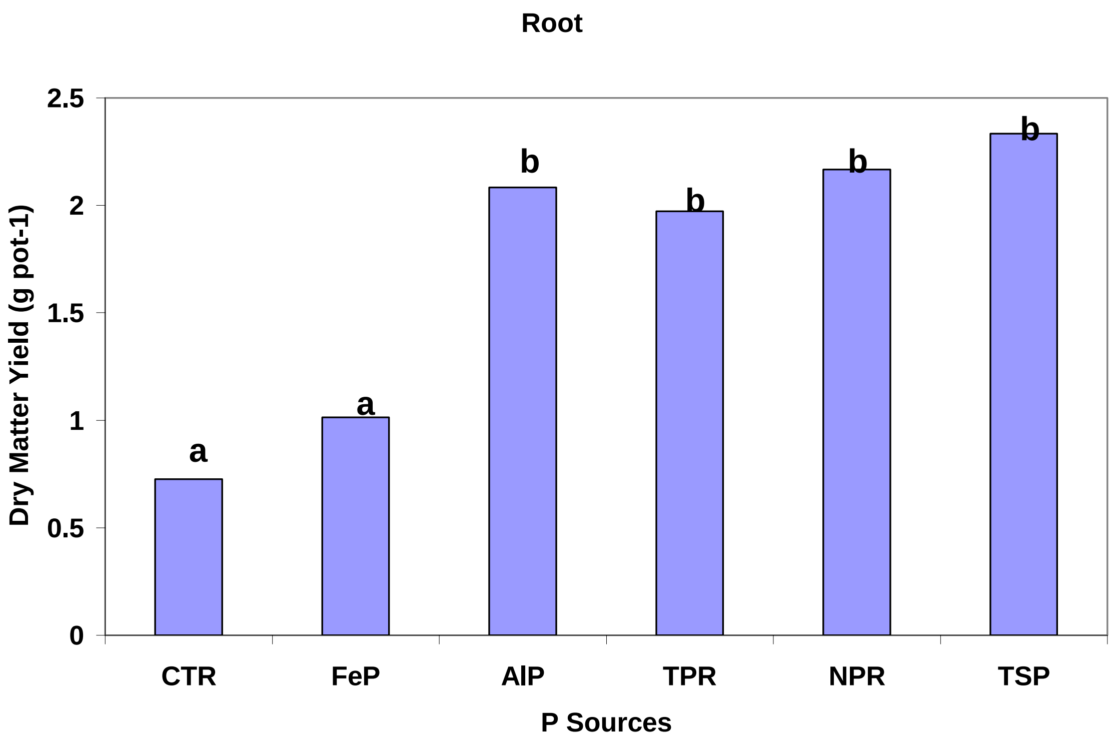


***Iron phosphate (Fe-P)**
Aluminum phosphate (Al-P)
Tilemsi phosphate rock (TPR)
North Carolina phosphate rock (NPR)
Triple superphosphate (TSP)

Fig. 5.10 The effect of triple superphosphate (TSP) treatment on P uptake by *Cassia tora*, greenhouse 2004

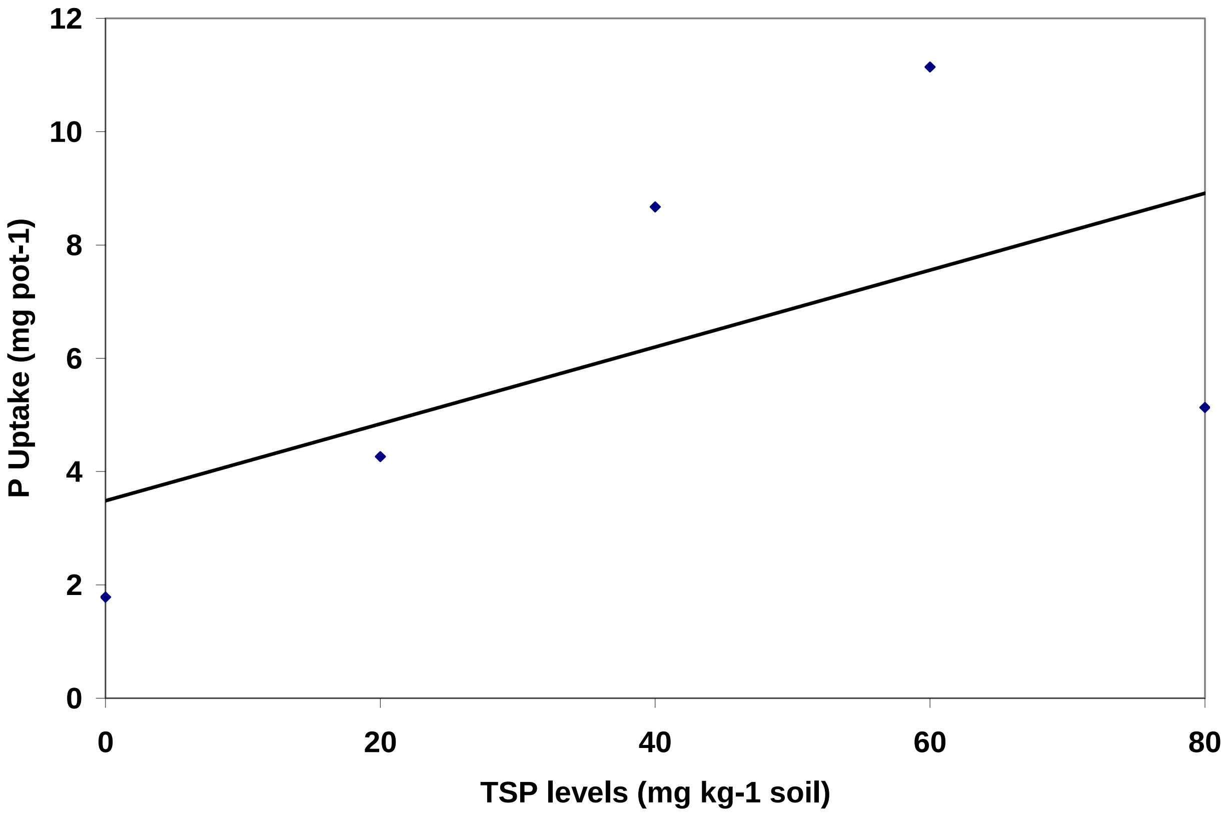
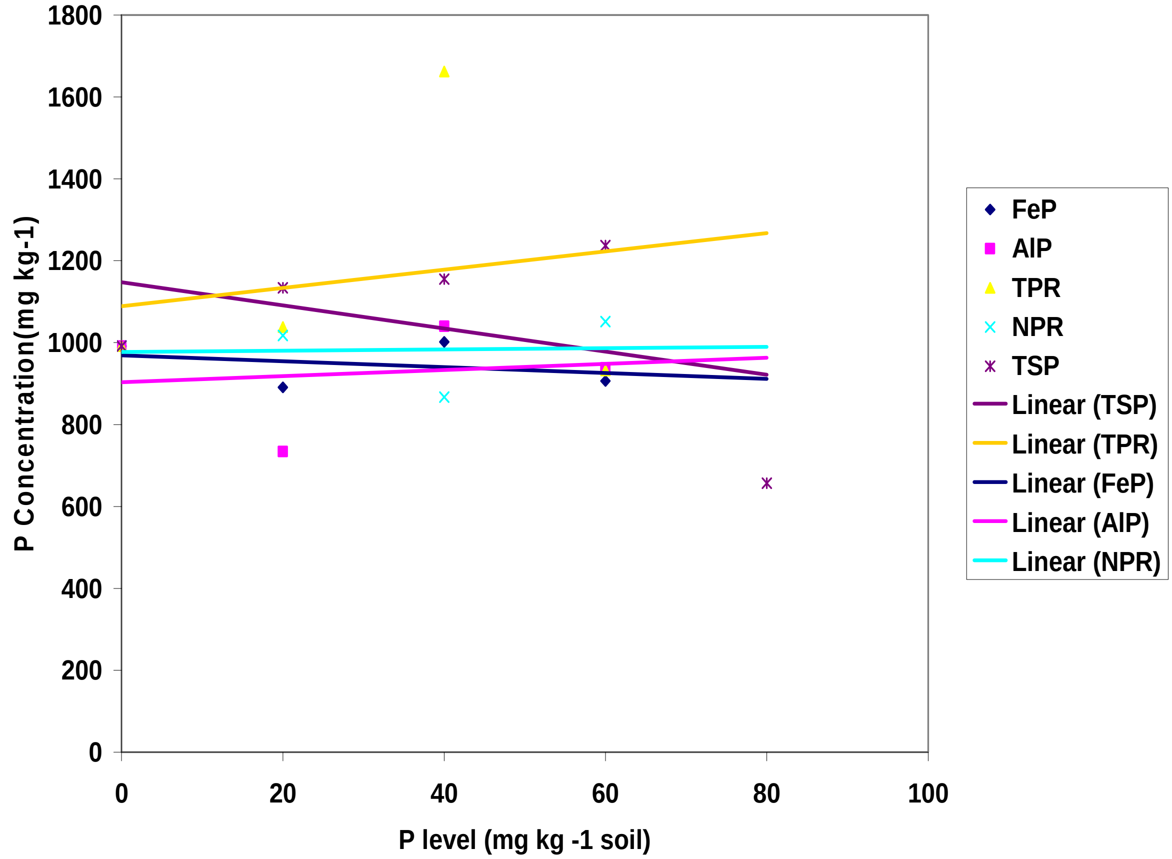


Fig. 5.11 Relationship between total P concentration in *Cassia tora* and P levels, greenhouse 2004



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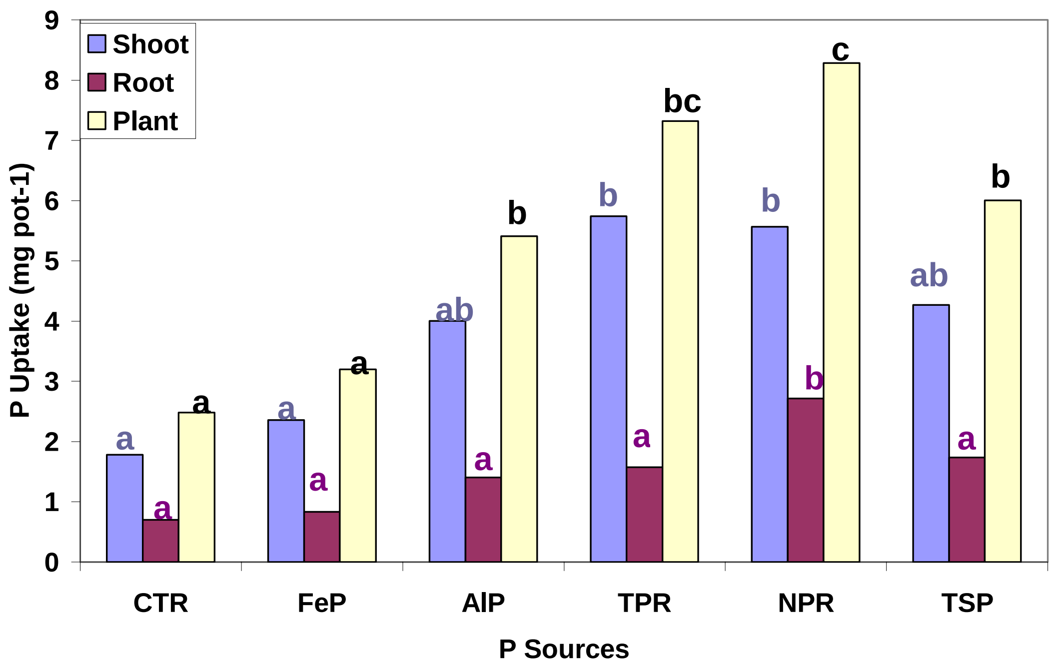
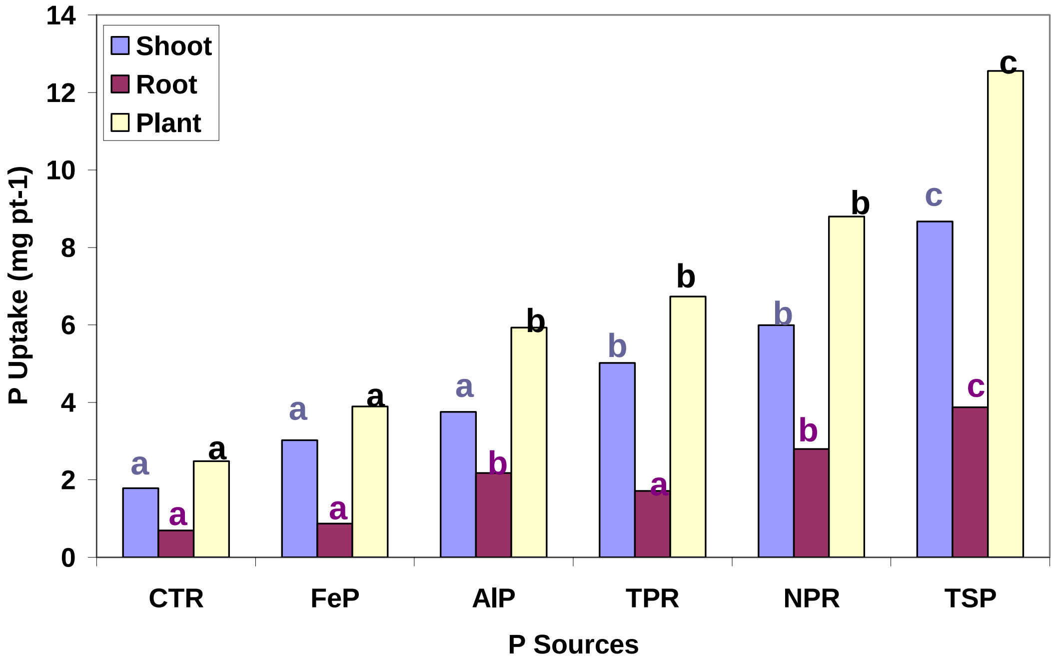


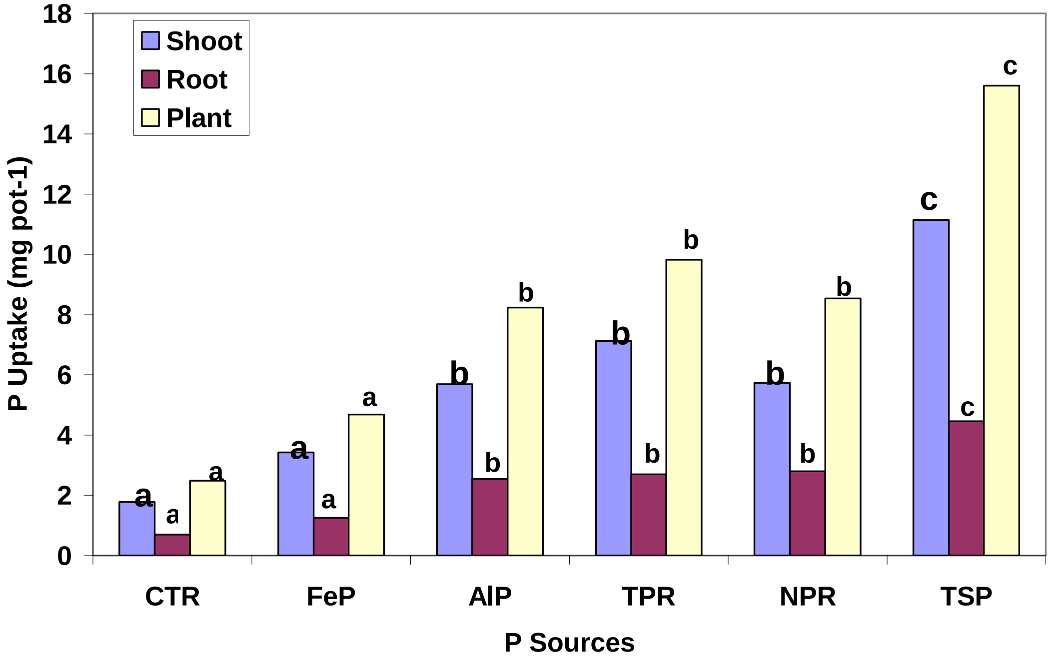
***Iron phosphate (Fe-P)**
Aluminum phosphate (Al-P)
Tilemsi phosphate rock (TPR)
North Carolina phosphate rock (NPR)
Triple superphosphate (TSP)

Fig. 5.13 Effects of various soil applied P sources at a rate of 40 mg kg^{-1} on P uptake by *Cassia tora***,** greenhouse 2004



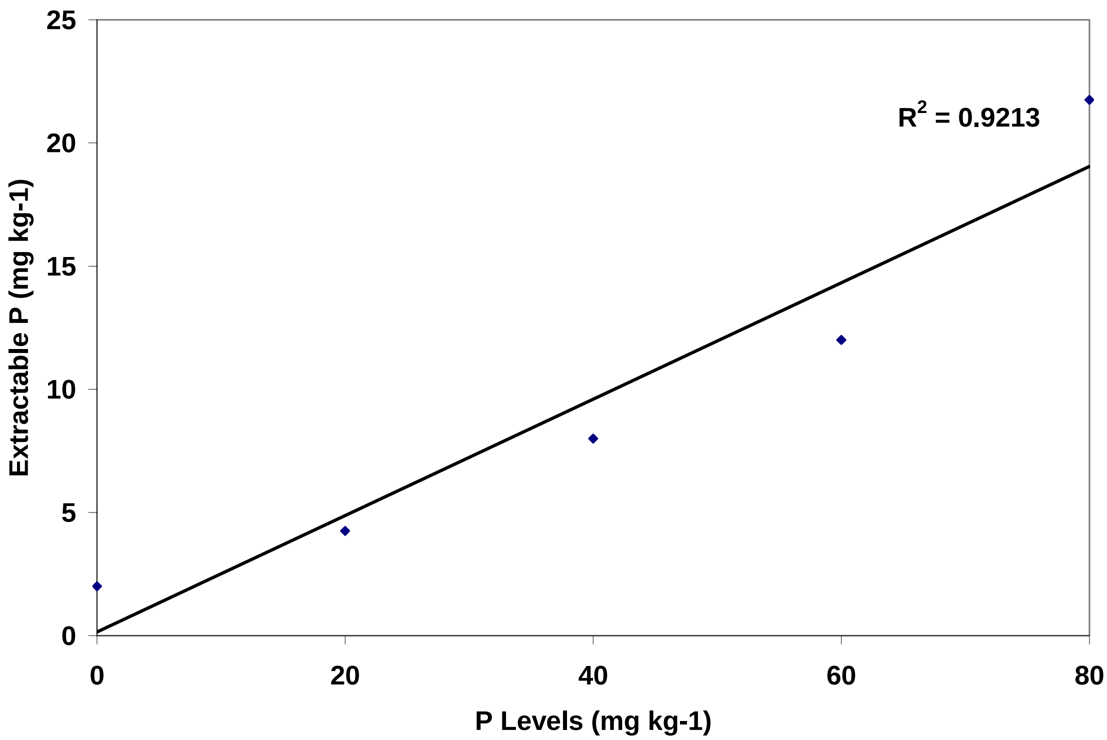
***Iron phosphate (Fe-P)**
Aluminum phosphate (Al-P)
Tilemsi phosphate rock (TPR)
North Carolina phosphate rock (NPR)
Triple superphosphate (TSP)

Fig. 5.14 Effects of various soil applied P sources at a rate of 60 mg kg^{-1} on P uptake by *Cassia tora*, greenhouse 2004



***Iron phosphate (Fe-P)**
Aluminum phosphate (Al-P)
Tilemsi phosphate rock (TPR)
North Carolina phosphate rock (NPR)
Triple superphosphate (TSP)

Fig. 5.15 Extractable P as measured by Mehlich I extraction for soil samples treated with triple superphosphate (TSP) under *C. tora* growth, greenhouse 2004



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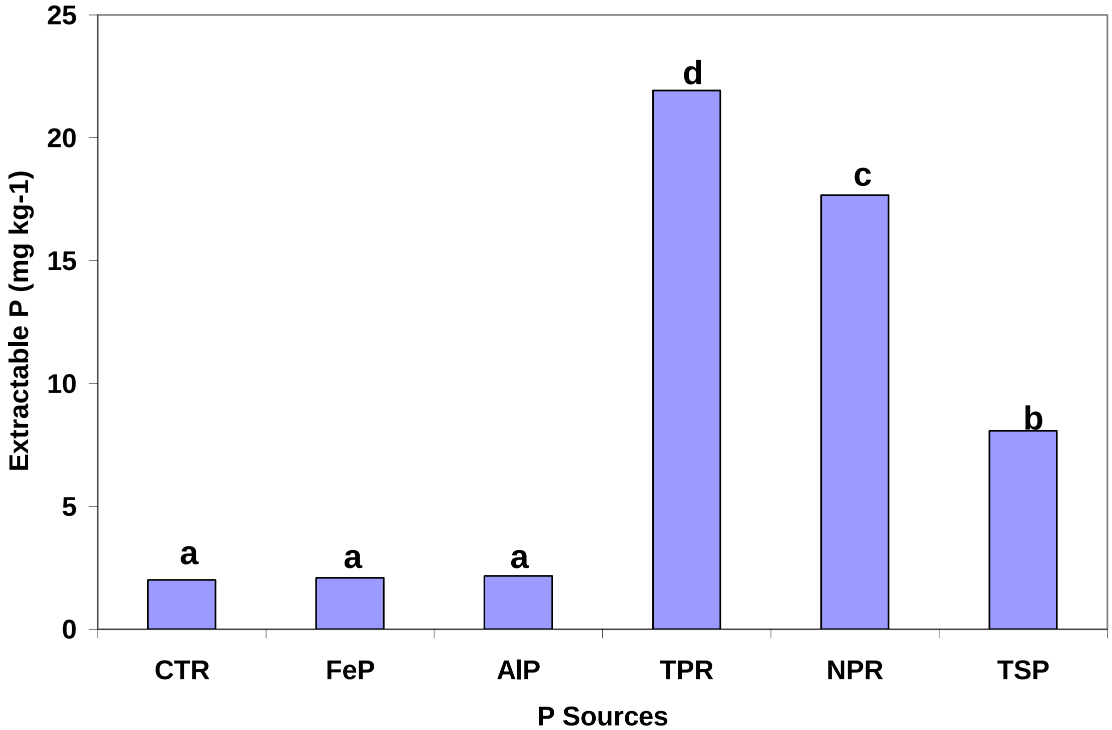

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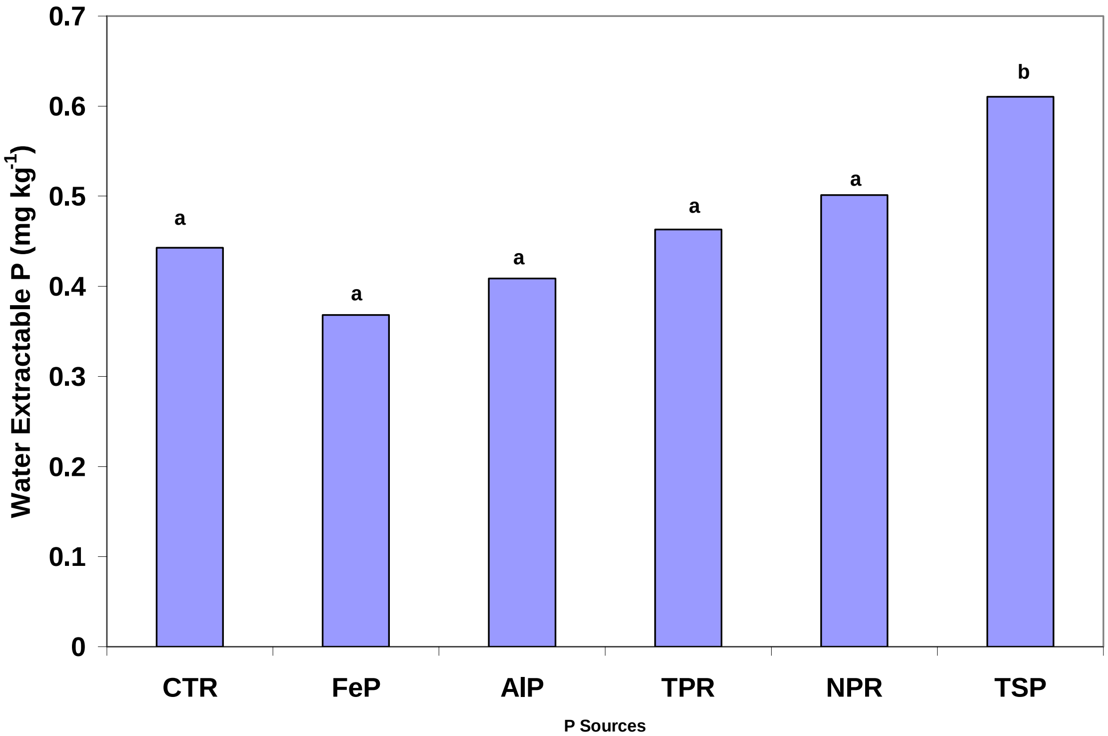

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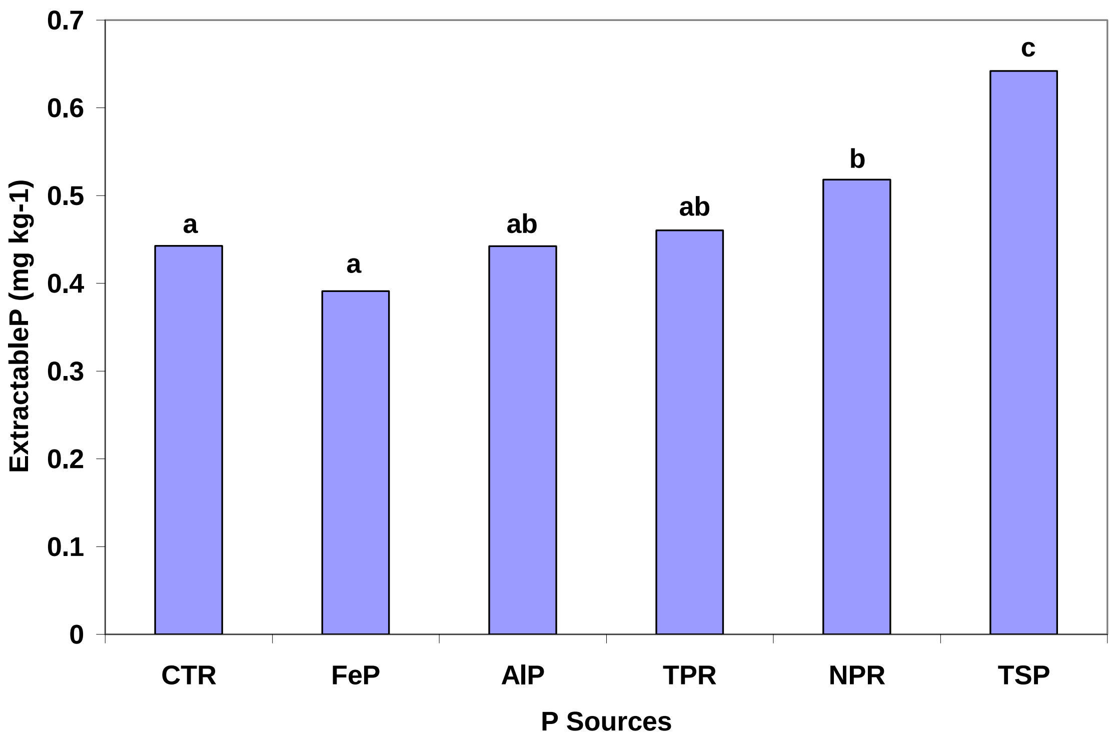
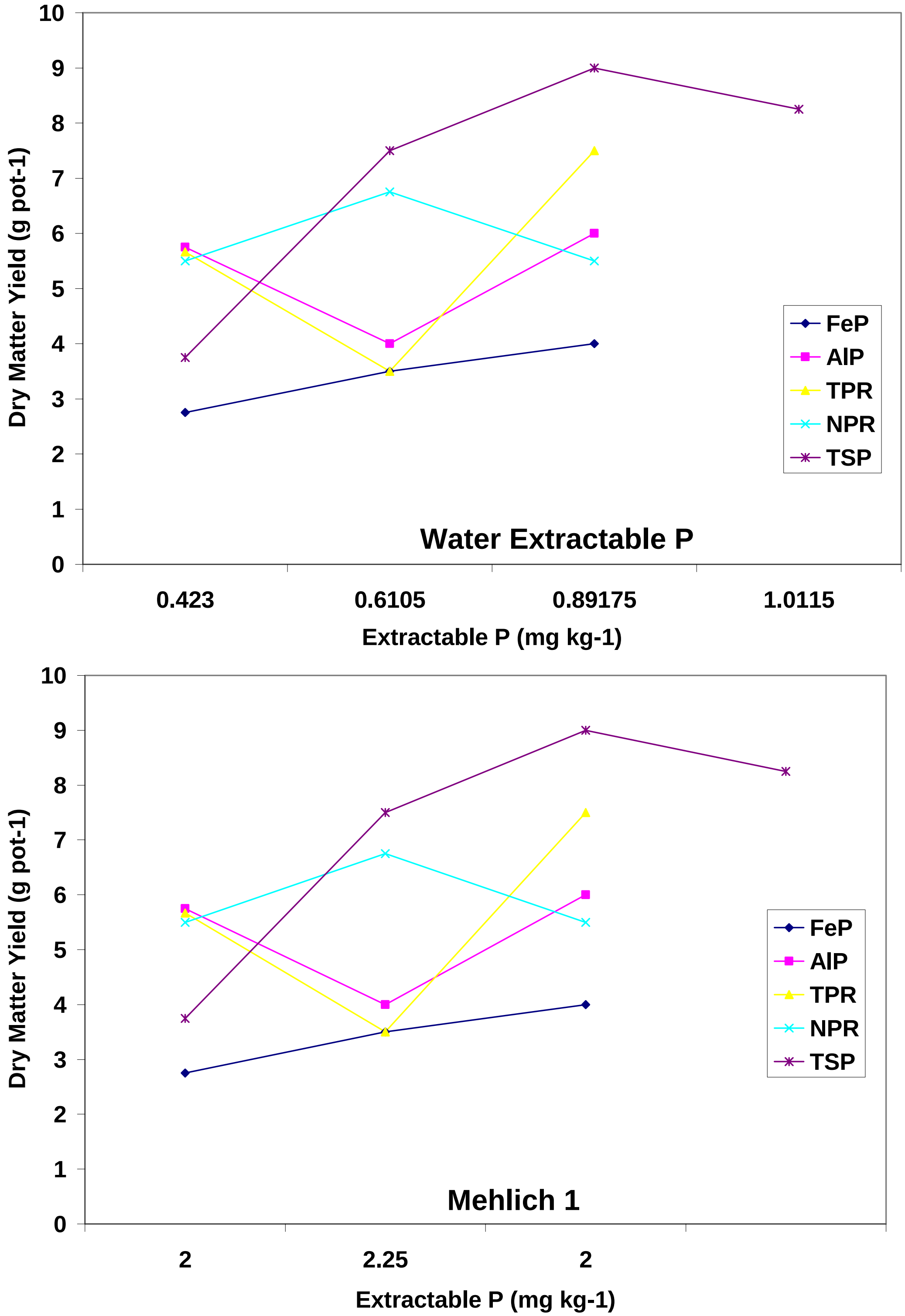


Fig. 5.19 Relationship between dry-matter yield of *Cassia tora* and extractable P for various P sources as measured by Water Extractable P (**A**) and Mehlich 1 (**B**) methods, greenhouse 2004



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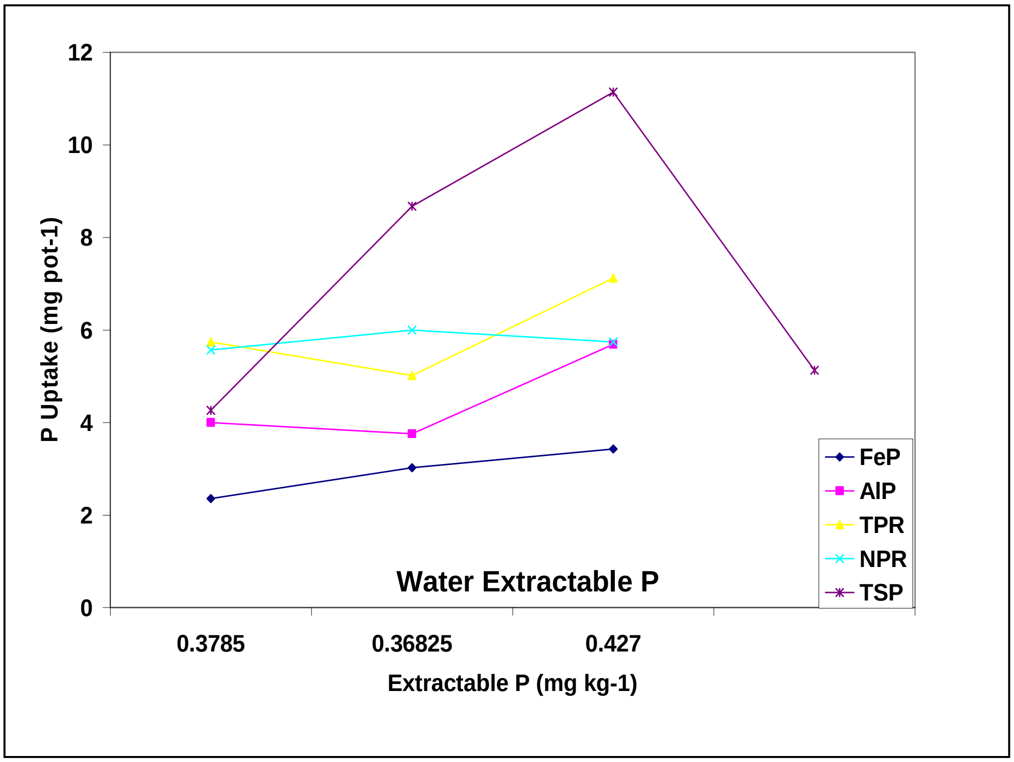

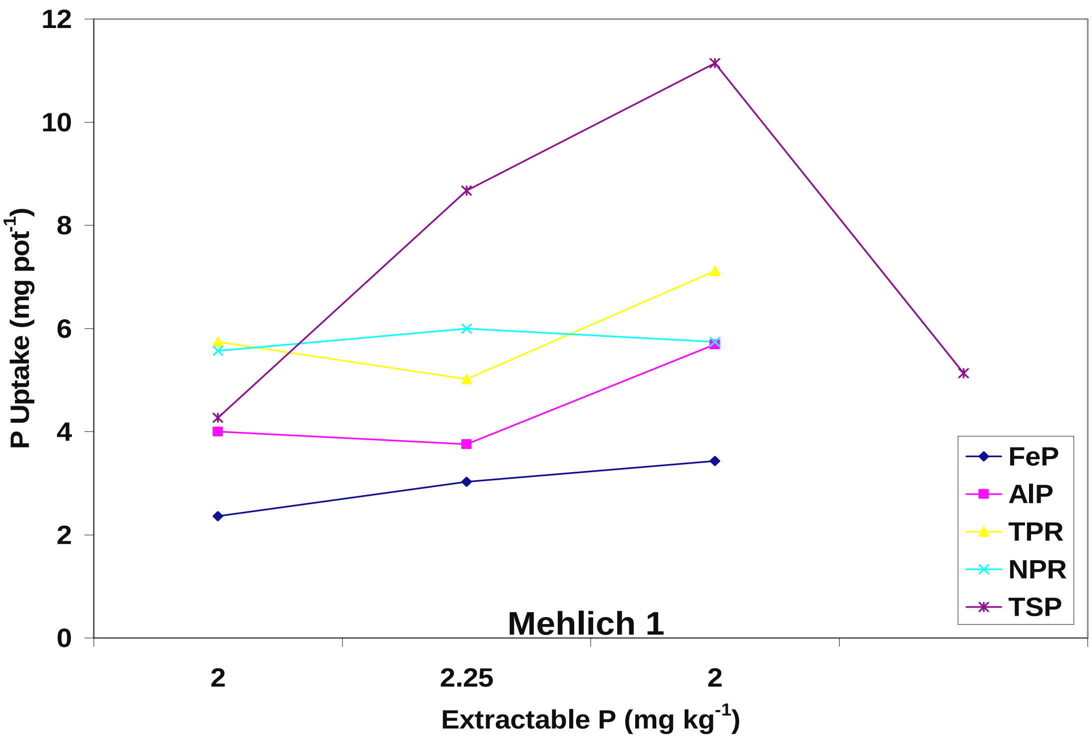

Chapter VI

Conclusions

The ecological, economical and social implication of alternative feed resources and the role of *Cassia tora*

The lack of pasture and forage resources has been a growing problem in the Sahel region of sub-Sahara Africa. Demographic growth, extensive row cropping, increasing herd size, high levels of exploitation of woody resources, and climatic fluctuations have all contributed to serious losses of plant biodiversity within this region. In addition, utilization of pastureland resources has become a major source of conflict among stakeholders. The overall focus of our work was to increase forage resources through better pasture management practices and better understanding of the ecological system through the identification and exploitation of a single plant, *Cassia tora*

Biological impact

If making *C. tora* into silage was to be adopted, it could affect the ecosystem within this region. As discussed earlier, exotic species can bring both positive and negative effects into an existing ecosystem. *Cassia tora* may have positive effects in the recycling of nutrients; however it is also aggressive in its growth and excludes grasses and other species from growing. In order to control *C. tora* without eliminating the plant, a cutting regime would be adequate. Ensiling *C. tora* could be a solution to two problems. If cut at the beginning of the growing season when still at the vegetative and leafy stage, the quality of the forage material would be optimum for conservation and feeding as silage to small ruminants during the dry season. In addition, it would allow other species to emerge and persist early in the season. Because *Cassia* has prolific seed production, harvesting the plant before it sets seed would control its growth and may make it ecologically more acceptable. In turn, a shifting in plant population with an increase and coexistence of various species might occur. Some might raise the question of the risk of exterminating *C. tora* over time if the plant is not allowed to enter the reproductive stage and regenerate. In order to prevent any loss in biodiversity, stakeholders need to understand that cutting or grazing any plant has to be done in a controlled and sustainable way, and like any other plant, *C. tora* must be managed in a sustainable way. If the plants were cut at different stages of maturity, it would allow some to seed for regeneration. However, Hien (1997) states that *C. tora* produces heterogeneous seeds that can extend the germination process over several weeks. Thus, if the plants germinate and grow at different times, it would be hard to exterminate *Cassia*, even if it is cut at optimal times for making silage.

Stage of maturity is critical to the management of *C. tora* both for reproduction and ensilage. The results of the silage experiment showed that even at late stage of maturity, *Cassia* silage was of acceptable quality. However, in order to allow other plants to germinate and establish within the pasture plant community, cutting *Cassia* at a vegetative stage when it is not tall enough to over-shade other species would reduce competition.

The role of *C. tora* in soil fertility is equally important to that of the management of plants in a pasture. Recent research revealed the ability of some plants to access insoluble phosphates in phosphate-poor soil, and increase the pool of available phosphate for succeeding crops. A recent research project by the International Crop Research

Institute of the Semi Arid Tropics (ICRISAT) showed many beneficial effects of two legumes, chickpeas and pigeon peas (study cited in chapter V), and a singular ability to cope with poor growing conditions. Some of the beneficial effects included an increased available P pool in the soil, an increase in water infiltration, and a decrease in crust formation. The ability of *C. tora* to persist and out-compete other species in the Sahel suggests that *C. tora* may also enhance the physical and chemical properties of the soil.

Socio-economical impact

Livestock are central to the livelihoods and existing production systems in Madiama. Field crops and livestock are the dominant production systems, with each generating 46.2% and 34.4% of the community income, respectively (Kabore, 2001). Livestock provides the commune as well as the country with meat, milk, leather, and wool products. Livestock exports to neighboring coastal countries where livestock production costs are much higher are an important source of national income. In Madiama, goats and sheep are mostly kept in the villages and fed by women. In Nérékoro, women are responsible for the fattening of animals and for milk production. Increasing the feed supply, especially during the dry season, would increase meat, milk, skins and fiber production.

Brewster *et al.* (2001) stated that any development strategy for the Madiama economy should focus on the livestock sector. Such focus points to the importance of pasture management. Improving pasture management improves pasture productivity and provides higher quantity and quality feed for livestock, thereby lowering livestock production costs and raising the women’s income. The ensiling of *C. tora* requires few inputs and complicated technologies, because labor is the most important input in this process. The use of locally available equipment and the reliability and repeatability of the ensiling process makes *Cassia* silage a sustainable source of feed. A study showed that crossbred cattle in Guinea savanna fed ensiled cereal crop residues can at the very least be maintained and possibly gain weight during the dry period.

An economic analysis is necessary to characterize the potential economic benefits of *Cassia* silage. This feeding option would be a supplementary feed that could give rapid and significant returns on investments. In addition, it is a reliable and repeatable process that could be done with any plant species of relatively good quality. In conclusion, based on our quality assessments, *Cassia* silage has a potential to be sustainable and economically feasible solution to feed shortages during the dry season in Madiama. The social and economic impacts of using a simple tool could far exceed the inputs for *Cassia* silage. If the net benefits of using a production system with *Cassia* silage exceed the net benefits of using a production system without *Cassia* silage, then *Cassia* silage is economically beneficial.

Another possible benefit to the production system in Madiama is the increase of local and natural fertilizer use, such as PR. Although our primary objective was to look at an indigenous plant's ability to thrive in low soil P environments and possibly increase the pool of available P in the soil; the results of our study showed that Tilemsi PR, which is local to Mali could increase *C.tora* productivity by 178%. The restoration of the natural resource base with Tilemsi PR is to be seen as an amendment that improves soil fertility and constitutes a long-term contribution to enhanced food security. The community can benefit from increased agricultural output while rebuilding the depleted natural resources, thus, PR application can be considered a capital investment (Gerner and Baanante, 1995).

Recommendations for future research

- Further research is needed to examine the toxicity of *C. tora* and to look at the effect of the ensiling process on these toxins.

- Research should expand to include more indigenous plants as potential feed sources
- Animal feeding trials are necessary in order to evaluate the true feed values of *Cassia* silage and perform economic analysis for large scale application.
- In order to account for biological factors, such as mycorrhizal activity, root architecture and rooting depth , *C. tora* and other indigenous plant's uptake and utilization of P need to be evaluated under field conditions.

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Vita

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