Effects of Environmental Factors on Net Primary Production of the Tropical Wet Savanna Grassland

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ชื่อวิทยานิพนธ์ ผลของปัจจัยทางสภาพแวดล้อมที่มีต่อผลผลิตปฐมภูมิสุทธิ
ของทุ่งหญ้าแบบซาวันนาชื้นในเขตร้อน
ผู้เขียน นางสาวอนุสรณ์ ศักร์ภพน์
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บทคัดย่อ

ผลการศึกษาผลผลิตปฐมภูมิสุทธิ ของทุ่งหญ้าแบบซาวันนา ในภาคใต้ของประเทศไทยเป็นรายเดือนในรอบหนึ่งปี โดยประมวลผลจากส่วนที่อยู่เหนือดินและส่วนใต้ดินในสภาพที่ถูกเผาและไม่ถูกเผา พบว่าอัตราการผลิตปฐมภูมิสุทธิเฉลี่ยต่อปี ไม่มีความแตกต่างกันระหว่างหญ้าที่ถูกเผาและไม่ถูกเผา (1493.30 และ 1453.13 กรัมต่อตารางเมตร ตามลำดับ) จากการวิเคราะห์ตัวแปรพหุคูณจำแนกประเภทของผลผลิตปฐมภูมิสุทธิกับตัวแปรทางสภาพแวดล้อมพบว่า 1. การเปลี่ยนแปลงของผลผลิตปฐมภูมิสุทธิ จะมีความสัมพันธ์เชิงบวกกับช่วงความยาวนานของแสงอาทิตย์และปริมาณน้ำฝน ส่วนศักยภาพการคายระเหยของน้ำและอุณหภูมิของอากาศ มีความสัมพันธ์เชิงลบ 2. ศักยภาพการคายระเหยของน้ำและช่วงความยาวนานของแสงอาทิตย์ สามารถอธิบายความแปรปรวนของผลผลิตปฐมภูมิสุทธิได้ดีกว่า ปริมาณน้ำฝนและอุณหภูมิของอากาศ สมการจำแนกประเภทสามารถจำแนกได้ถูกต้อง ร้อยละ 74 และใช้ทำนายผลผลิตปฐมภูมิสุทธิเมื่อมีอัตราการสร้างที่เพิ่มขึ้นได้ดีกว่า เมื่อมีอัตราการสร้างที่ลดลง

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ABSTRACT

Net primary production (NPP) of a savanna grassland in southern Thailand was estimated at monthly intervals during a year-long study for below and above ground production, in burnt and unburnt conditions. The mean annual rate of production was not different for burnt and unburnt areas (respectively, 1493.30 $g.m^{-2}$ and 1453.13 $g.m^{-2}$). Multivariate discriminant analysis of NPP and environmental variables showed : 1. changes in NPP are positively correlated with sunshine duration and precipitation and negatively correlated with PET and air temperature, 2. PET and sunshine duration are able to explain variation in NPP better than precipitation and air temperature. The discriminant function could classified correctly about 74% of the cases and could predict better for increasing NPP than decreasing.

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CHAPTER 1

INTRODUCTION

1. Introduction

Various attempts have been made to establish a relationship between primary production of tropical vegetation and environmental factors in various parts of the world in order to quantify the conversion of carbon in terrestrial ecosystems. In this decade of environmental concern about global warming, knowledge about the global bioproductivity, in which carbon plays a major role, is essential to predict the consequence of today's actions on tomorrow's world. Primary productivity is a measure of the rate at which plants assimilate, by using the energy from sunlight, carbon dioxide from the atmosphere and transform it into carbohydrates. It is estimated that about 563 gigaton(Gt) of carbon is incorporated in the Earth's plant life annually, while in 1986 the atmosphere held an estimated 730 Gt of carbon (de Groot, 1990). Among terrestrial vegetation, tropical forest is significant in the global carbon budget. The role of trees is usually emphasized by ecologists and environmentalists, while grassland, which also covers huge areas worldwide, is often not mentioned at all. However, recently, a study of the United Nations Environment Programme (UNEP) reported that compared to the other types of vegetation, productivity of grassland is second only to tropical forest (Hall,1990). At a time when rising atmosphere CO_2 levels have become a major environmental concern, it brings also to the potential of tropical grasslands as a major CO_2 sink comparable to that of the rainforest.

The bioproductivity of each natural grassland ecosystem, including those in the tropics, is known to be regulated by its environmental conditions. To understand the quantitative relationship between the bioproductivity and the fluctuating abiotic environment is, therefore, important for predicting the responses of community productivity to changing conditions. As suggested by Steinhorst and Morris(1977), it is possible to use combined climatic data at each particular period of the growing season to predict the growth of natural vegetation. Tropical wet savanna grassland has the unique ecological characteristic of being wet which effects plant growth and the development of the community as a whole, so it differs from other tropical grassland ecosystems(Bourliere and Hadley,1983). The pronounced characteristic of the grass stratum is that it is often burnt in the dry season, whereas the main growth occurs in the wet season (Kamnalrut and Evenson,1985). The relationship between its productivity and environmental factors, however, has yet not been studied closely. A thorough knowledge of how this type of savanna grassland community responds to climatic factors is, therefore, urgently required.This study aims to do with the following objectives:

1.1 to measure vegetation dynamics in terms of biomass and net primary production by taking account of above and below ground plant organs.

1.2 to determine the relationship between climatic variables and changes in net pimary production.

1.3 to compare the production patterns for burnt and unburnt area.

2. Review of literature

2.1 Net primary production

According to Odum (1971), primary productivity is defined as the rate of energy stored by photosynthetic and chemosynthetic activities of a producer or organism in the form of organic substance which can be used as food materials. Net primary productivity is the rate of organic matter accumulated in plant tissues in excess of the respiratory utilization during the measurement period. Some other terms of " net primary productivity " are " appearance photosynthesis" and "net assimilation".

Several methods to measure primary productivity are described by Odum (1971). For instance, in aquatic ecosystems productivity can be estimated by measuring dissolved oxygen (by the light and dark bottle method), dissolved carbon dioxide, or the change of pH and the disappearance of raw material minerals. In terrestrial ecosystems, productivity can be estimated by measuring carbon dioxide concentration, the harvest of biomass or by radioactive transfer. Measurement of chlorophyll content can be used to estimate productivity both in aquatic and terrestrial situations.

Although there are several techniques for determination of primary productivity of terrestrial vegetation particulary above ground, the harvest method has been claimed to be the simplest and most reliable method (UNESCO, 1979).

2.2 Significance of the primary productivity

2.2.1 Ecological aspects

On our planet, plants are the primary producers to fix carbon dioxide and convert light energy to biotic substances. They provide food, and hence potential energy to other types. This "energy" passes through a series of organisms in the process of eating and being eaten repeatingly. This path is refered as the food chain. The rate of energy flow through each trophic level can be measured on fresh or dry weight basis and can be expressed in terms of calories. To evaluate the production of ecosystem, it is important to consider the nature and magnitude of the energy drain and energy subsidies to maintain biological structure (Odum, 1971).

2.2.2 Primary productivity and environmental effects

The so-called greenhouse effect, the global environmental warming-up is expected to alter the physical and biological conditions of life on Earth. Atmospheric carbon dioxide, one of the important of "greenhouse" gases, currently increases annually about 1.5 ppm, and this is already going on for the past 15 years (Houghton and Woodwell,1989). Besides the waste products of living beings, carbon dioxide (CO_2) is the essential material for photosynthesis. Since pre-industrial time, carbon dioxide fixed by vegetation and carbon dioxide released into the atmosphere had been neatly balanced. Now, human activities shift the balance to a different equilibrium, causing a change of the physical parameters of the atmosphere and consequently affecting the physical conditions for plants, animals and human. As the expression "greenhouse effect" indicates, it is likely that the temperature at the Earth surface will increase. This may change bilogical conditions for certain plants and plant communities dramatically, not only in the sense of a higher than optimal temperature for growth, but also in relation to the evaporation of available surface water, flooding, desertification, burning of vegetation, etc. It is feared by environmentalists and other scientists that changing of the equilibrium of say around 1860 to a new one, hopefully still in the next century, may cause serious adaptation problems for life on Earth, not in the least for human. These problems are becoming a prominent issue in international politics. It is generally felt that worldwide carbon dioxide intake, emmission and storage should be looked into more closely and the amounts, if possible, should be quantified precisely. Global primary productivity quantification is the way to determine the rate of carbon cycling through vegetation around the world.

Many authors have tried to estimate the primary production of various plant communities as well as the amount of carbon dioxide released. The world forests are considered as a large carbon dioxide reservior which contains three times as much carbon as what is contained in atmospheric carbon dioxide (Allen,1980). In the process of photosynthesis, terrestrial plants utilize about 100 billion tons of carbon from the atmostphere per year or about 14 % of the total atmostpheric carbon content (Houghton and Woodwell,1989). The amount of carbon released into the air annually by forest clearing, however, is estimated between 1-2 Gt. Burning off savannas contributed three times as much carbon dioxide to the atmosphere than burning down rainforests. Data extrapolated from three UNEP terrestrial grassland sites suggests that the global flux of carbon into the atmosphere from burning tropical grassland fall in the range of 2.4-4.2 Gt per year (Hall and Scurlock, 1990a).

The accurate determination of the primary production to quantify the amount of carbon dioxide being fixed by these biological reservoirs is thus essential to comprehend the carbon dioxide problem.

2.3 Bioproductivity of grassland

2.3.1 Above-ground and below-ground productivity

Grassland productivity has been studied not only in the biological realm as the IBP studies but also in an integrated way for its socio-economic aspects by UNESCO, FAO and UNEP, aimed at development and management of this resource(UNESCO, 1979).

In the beginning, measurement of grassland productivity referred only to above ground biomass (Blydenstein, 1962: quoted in UNESCO, 1979: 130) and defined production potential only in terms of the matter available for transformation by livestocks. The determination of below ground parts or the estimation of the relationship between above ground and below-ground amounts, known as shoot root ratio, seems to be a weak point in most terrestrial ecosystem research work. This is in particular the case for grassland with extensive, underground root systems, compared to the size and volume of the shoots.

In the past it was thought that grassland communities were not as productive as rain forests. Recently, productivity of the world ecosystem, as estimated by many authors, indicated that, compared with other ecosystems, net primary production of grassland almost equals that of tropical forest, although the standing biomass is 7-10 times less than luxury forests (Houghton and Woodwell, 1989). The methodology for measuring primary production by considering both above and below-ground production has been developed for tropical grassland (Roberts, et al., 1985). Calculation at the three tropical grassland sites in Mexico, Kenya and Thailand, where full account is taken of losses of plant organs above and below-ground, estimated productivities are up to five times higher than were obtained by the method based on a change in above-ground vegetation mass alone (Long, et al., 1992). These results give new implications as to production and turn over estimations of plant biomass in those grassland communities and for prediction of amounts involved in global carbon cycling.

2.3.2 Savanna as a type of grassland

Savanna is a physiognomic term used as a descriptive of vegetation type by scientist in several disciplines. The vegetation information is classified in several systems, yet this term has precise definition or an exclusive circumscription (Johnson and Tothill, 1985). However, this such a vegetation type is generally agreement defined by structure and function which have continuous graminoid layer characteristics. According to Johnson and Tothill (1985), savanna vegetation is characterizied by a continuous graminoid stratum, more or less interupted by tree or shurbs. Besides, based on the vegetation structure, the climatic regime and the type of land use are the two important concepts for characterizing savanna namely, rainfall distribution, temperature and the regular use of fire both naturally and purposely.

Richards (1952) as quoted by FAO (1976) had described the savanna community as a name applied to plant communities of varied physiognomy and status found over a wide range of climatic condition; some are serial stages, others are certainly stable climaxes.Savanna on which trees are dominant (with or without a continuous ground-cover of grasses) may be a climatic climax, but many types of savanna should be regarded as fire-climaxes. Open savannas with trees growing scattered or in occasional clumps, and treeless grasslands may arise by the degradation of the forest or savanna woodland by excessive cultivation of burning but in some cases they are probably edaphic climaxes due to local soil conditions unfavourable to the growth of trees.

Bourliere and Hardley (1983) view savanna a representing a transition zone or gradient from closes forest to open desertic steppe.

Savanna is rather accepted in seasonal system in tropic than in temperate. Wet savanna occured in area receiving more than 1500 mm annual rainfall where sites have impeded drainage and water logging and flooding occurs annually for extended periods (Johnson and Tothill, 1985). The african savanna is the best known of all tropical savannas which is the transition zone of grasslands lie between the humid tropical forest and hot deserts. The tropical savanna in place is increasing as the forest cover is destroyed. After the forest has been cleared, the stages of secondary succession are dominated by herbaceous species. Such stages are usually a transitional forest. In case where there are repeated human interventions through fire or new clearing, these secondary stages may change into a savanna.

Herbaceous and woody products are both contributing to the production of savanna community. The deeply rooting capacity of trees gives them an enlarged and non competitive environment for both water and nutrient extraction. The balance of savanna ecosystems is maintained by suitable distribution of tree cover. It is a controlling factor in savanna ecosystem composition, structure, productivity and dynamics. Trees appear to have an influence on the physio-chemical factors of the environment. Compared to open areas the amount of organic matter and the variety of mineral elements in the soil beneath the trees is greater in the upper horizon and the maximum temperatures are lower. Leaf-fall from woody plants after a bush fire has passed are indispensable in protecting soils against erosion.

The relationship between herbaceous and woody production is thought to be quite complex linked as it is to the environment, and bushfire occurence causes an additional complication.

2.4 Factors effecting primary production of natural grassland

In general, several factors including climatic, edaphic and biotic elements govern plant growth and development, hence also primary production. Physiological studies usually consider the importance of a single factor such as light or temperature or precipitation for monospecific communities or crops, but for a natural community they do not give us a single answer (Steinhorst and Morris, 1977). The environmental factors influencing productivity are possibly considered to determine community productivity since both are combined effect and in isolation. By using some combined abiotic variables, Steinhorst and Morris (1977) showed that over a large portion of the globe, the growing season of natural savanna mainly is determined by precipitation and temperature. They suggested that more factors may govern the growing season in the tropic than in the temperate zone.

2.4.1 Precipitation

Precipitation in this context will be refered to amount of rainfall. Rainfall is the climatic factor which shows the greatest variation both in time and space (Doorenbos, 1977). The three main characteristics of rainfall, regarding the usefulness for the growth of natural vegetation are : amount, intensity and frequency. The report of UNESCO (1979) reveals that the relationship between rainfall and savanna productivity depends on the factors in the following manner : The structure of tropical vegetation parallels the rainfall gradient and strongly depends on the severity of the dry season. These two factors cannot be separated and have little meaning when considered in isolation. Production can only be linked to annual rainfall in fully arid or semi-arid conditions, but this simple relationship become blurred when the rainfall is over 400 mm. Then the correlation found by Walter(1964) is no longer applicable. Panderya, et al.(1974) noted that the difference in rainfall caused little change in the above ground biomass but may lead to marked variation in the below-ground biomass. Comparible results have been observed by Hopkins (1970) in periforest savannas in Nigeria but considerable variation did not allow any pattern to be identified in the relationship between rainfall and plant growth.

The minimum precipitation needed for proper plant growth is known in terms of water requirement. It is the depth of water needed to meet water loss through evapo-transpiration (Doorenbos, 1977). The estimation of plant water requirements has been reported in FAO Irrigation and Drainage Paper No 24(Doorenbos, 1977). The difference between precipitation received and water loss by plant and soil is defined as water balance (Frere and Popov, 1979). There are very few estimates of the water balance for the entire ecosystem in tropical savannas, even if the water regime of its soil is well-known. Information on the effect of hydrological constraints on vegetation throughout the growth cycle and, in particular, on the way in which plant use water, is lacking. The total lack of eco-physiological studies is considered a serious drawback in understanding the rainfall - plant growth relationship (UNESCO, 1979).

Research by Lammotte (1967) at Lamto, Ivory Coast, indicates that in all physical and environmental studies, the interaction between the rainfall distribution (in time), soil type, vegetation structure, and vegetation cover should be stressed and certainly in studies on soil water.

2.4.2 Evapo-transpiration

Evapo-transpiration is the sum of transpiration by the plants and evaporation from the soil surface (Doorenbos, 1977). Dastane(1974) states that the level of evapo-transpiration is controlled mainly by three factors, namely, plant characteristics (extent of ground cover and stage of growth), water availability in the soil, and meteorological parameters or evaporative demand. Maximum or potential evapo-transpiration (PET) occurs when the soil water is non-limiting and the crop is in an active stage of growth with full ground cover.

Potential evapo-transpiration can be computed from meteorological data. Several formulae are available but it is noticeable that none of them suits all situations perfectly (Doorenbos, 1977).

The details of the four well-known methods (Blaney-Criddle, Radiation, Penman and Pan Evaporation) to estimate evapo-transpiration based on climatic data are described in FAO Irrigation and Drainage Paper No 24 (Doorenbos,1977).

For a given location, evapo-transpiration will show less variation from year to year than does rainfall. The variation depends mainly on the degree of cloud cover. In many areas evaporation may not change substantially for hundreds of kilometres where the climate is similar (Doorenbos, 1977).

Grass evapo-transpiration has a direct relationship with dry matter production for pastures at various latitudes (Stanhill,1960: quoted in Doorenbos, 1977: 61). Rosenzweig (1968) has shown that, on a world scale, actual evapo-transpiration correlates strongly with net above-ground production for vegetation in an ecological balance situation. Lieth and Box (1972) have been able to model relationships between rainfall, actual and potential evapo-transpiration and net above ground primary productivity on a global scale, and have depicted the results on a world map.

However, the report by UNESCO (1979) suggests that it is only possible to use the estimates of evapo-transpiration in environments, when all factors are fairly well controlled. This is not the case for complex natural ecosystem. These hypotheses are at present still far from being applicable in an arbitrary situation.

2.4.3 Solar radiation energy

Solar energy provides two essential needs for plants: light for photosynthesis and for many other functions, and thermal condition for normal physiological functioning.

The three characteristics of light which affect plant growth are duration, intensity (flux density) and quality of light.

Duration: the effect of photoperiodism on vegetative and reproductive stages is well-known as the classification of plants based on their photoperiodic requirement for floral into short-day long-day and day nutrual plants. Daylength is a function of latitude.

The intensity of light is the most important factor influencing the photosynthetic activity of plants. Light utilization by crops has two limitations: the maximum quantum yield at low intensities, and light saturation at high intensities. A minimum of 110 to 211 $cal.m^{-2}.day^{-1}$ is required for an effective photosynthesis, that is when the photosynthetic gas exchange is greater than the respiration (Blackman and Black, 1959).

For a single leaf measurements in the laboratory, it is known that in most crops and plants, the maximum day light intensity easily causes saturation (Arnon, 1972). However, in the field, even these high light intensities are rarely capable of saturating because light is not spread evenly over the active photosynthetic surface. As it passes by reflection and transmission through several layers of leaves, its intensity falls off exponentially with the path-length through the absorbing layer. The actual yield in the field is due to the upper part of the canopy mainly, where there is some degree of saturation. The lower leaves may contribute little on clear days and possibly show a negative net assimilation on cloudy or rainy days. As long as light saturation of the canopy as a whole does not occur, any increase in light intensity will increase productivity (Arnon, 1972).

Tropical grasses have a higher capacity for growth than temperate zone grasses. This is due to the great responsiveness of the plant to high radiation levels. They are well adapted to the hot dry sunny conditions of the tropics (Black, 1972). This is due to the fact that the tropical herbaceous species of open areas, especially grasses, are often of a C_4 type (Hatch, et al., 1967). The proportion of C_3 types especially among woody plants is much higher in shaded areas (Hofstra, et al., 1972). It has not yet been shown that C_4 plants have a higher productivity than C_3

plants in savannas which do not suffer from extreme aridity, in spite of their apparently better adaptation to the environment (UNESCO, 1979).

The intensity of light energy versus productivity relationship is usually studied by converting radiation into net primary productivity or by relating it to the efficiency of the plant community. The incident light conversion by various type of vegetations are described by Boardman and Larkum (1975). For instance, for temperate grassland it is 0.4 % and savanna converts only 0.2% of the incident light by means of the carbon cycle.

Wavelength as quality of light[1]: radiation within the middle ultra-violet part of the spectrum (250-350 mm) is harmful to most plants. Radiation in the near UV, and blue and green light (330-550 mm) has a photoperiodic effect, while light in the blue-green to red wavelength range (440-690 mm) is most effective for the photosynthesis. Beyond 740 mm, where the infrared spectrum start, radiative energy has practically

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[1] The term "light" refers to the visible part of the electro-magnetic radiation spectrum, but is often, be it incorrectly, used for the near-ultra-violet and the near-infrared spectral bands too. The correct expression for the UV and IR bands is "radiative energy", not"radiation", as this means the process of EM radiative energy transfer (Hempenius, personal communication).

no effect on the photosynthesis; its main effect is thermal, and it encourages respiration.

2.4.4 The fire factor

Bushfires or savanna-fire can have a direct effect on biomass production of their vegetation. There are three factors which may stimulate germination and growth in burnt areas (Hopkins, 1963). The first and main factor concerns the micro-climate: the temperature at ground level and of the air layers near the surface is raised, not so much because of the fire itself which is a short-term effect, but increase mainly during the following weeks due to the darkened bare soil, partly covered with black ashes, which adsorb solar radiation well. The second factor is the disappearance of dead leaves and other vegetation parts which eliminates competition and shading effects. The third factor is about the increased availability of useful minerals as they migrate more rapidly from the roots to the above-ground parts of the plants due to better exposure to sunlight.

Cattle owners burn grasslands every year or every second year to encourage the growth of new shoots and destroy pests. At the beginning of the growing season, the quality of production is high in crude protein (Braun, 1972). During the first six weeks of growth the crude protein production slows down gradually. This is rather pronounced in the grassland with a long growth period. The effect of burning on the availability of high quality fodder for their cattle seems a very real reason for the cattle owners to continue this practice.

After burning, the grass grows slowly and the cover is incomplete. Intense sunshine and early rains then cause the soil structure to deteriorate rapidly. Surface soil becomes more compact and less permeable and surface run-off as well as erosion are greater (Skovlin, 1972). Due to these effects, the burning of savannas is reported to lead to soil erosion, which consequently lowers the productivity of the land. And in case of low rainfall, fire will retard growth, diminish production and destroy hay.

Fire in grassland may result in a net loss of carbon from soil, and volatalisation of soil nitrogen may have feedback effects on primary productivity (Hall and Scurlock, 1990a).

2.4.5 The edaphic factor

Soil characteristics such as texture, nutrient status, and depth are important factors which determine the competitive relationship and growth rates of plants in a wide variety of environments. When nutrients are added to the soil, the species composition and productivity will change. The various herbaceous associations are directly linked to the percentage of C and N in the soil. The work of Anderson and Talbot (1965) and Braun (1972) revealed that above ground herbaceous production is relatively independent of the local climatic gradient but is associated with the soil catena. Total primary production in the Lamto savannas increases with the amount of soil organic matter and with improved drainage (Cesar and Menaut, 1974: quoted in UNESCO, 1979: 137).

A number of studies have analysed relationship between the physico-chemical characteristics of soils, especially water supply, yet few publications are concerned with the influence of the soil on the production of natural vegetation.

CHAPTER 2

METHOD OF STUDY

1. Field lay-out and data collection

1.1 Plot lay-out and sampling procedure

Burnt and unburnt areas were divided into a number of equal square plots. Each square was divided into a small quadrats of 0.1x0.25 m. A buffer zone of at least 0.5 m between quadrats served to protect against adjacency effect from nearby quadrats after harvesting. Each quadrat was designated with a unique number. A map of the site was prepared to plan random sampling procedures. Samples were collected monthly from March 1990 to March 1991. The areas to be burned were set afire in March 1990. Nine quadrats of burnt and unburnt plots the were harvested each month.

1.2 Net primary production data

By means of the harvested method based on the techniques to determine bioproductivity, net primary production was measured according to the UNEP project described by Roberts, et al. (1985). The method used was developed for tropical grassland and thus covers both below and above-ground production, and also accounts for losses through decomposition.

The above-ground biomass of the shoots was clipped at ground level from the randomly selected quadrats. All litter in those quadrats was also collected. Harvested biomass was sealed into labelled plastic bags along with a small quantity of water to prevent desiccation damage. The bags were stored at 2-5 °C to minimise post-harvest weight loss through respiration. Total fresh weight was measured, then a sub-sample of approximately a half of fresh weight sealed in a plastic bag and placed in and ice chest. In the laboratory, the dead vegetation was separated from each sub-sample, and the live material was classified into the four key species: Eulalia tripicata, Lophopogon intermedius, Fimbristylis tristachya and Dillenia hookeri and other grasses. All the plant material (sub-divided into dead and live material and litter) was dried to constant weight at 80 °C in an forced-draft oven before being weighed.

Below-ground biomass from each selected quadrat was sampled from the centre of the quadrat area by 5 cm diameter soil cores. Root materials were taken from soil cores at depth-ranges of 0-10 cm, 10-15 cm, and 15-30 cm. Roots were washed with running water in a 2 mm sieve, and were carefully separated into dead and live. Large structures were visually sorted into dead and live. The remainder were sub-sampled into approximately 2 g dry-weight sample, and were then carefully separated into the dead and the live catagories.Then the dead/live ratio of whole sample was estimated by extrapolation. All samples were dried to the constant weight at 80 °C before being weighed.

The litter-bag technique (Roberts, et al., 1985) was used to measure decomposition. The 2 mm mesh nilon bags, each of which filled with about 1-2 g dry weight of root litter and standing dead, were placed at 5 cm depth below ground (dead root), on ground level(litter), and in the canopy (standing dead). The bags were collected during the next harvest. The rate of decomposition was calculated as the proportion of initial dry weight lost within the month:

$r = (W_i/W_{i+1})/(t_{i+1}-t_i)$

where r = relative rate of decomposition

W_i and W_{i+1} = the dry weights of dead plant materials placed in recovered from the litter bags at time t_i and t_{i+1}, respectively.

1.3 Rainfall data

A raingauge was installed at the study site in open space at a height of 15 cm above the surface. The readings were taken daily at about 8 a.m.

1.4 Potential evapo-transpiration, sunshine duration and daylength data

The American pan class A evaporation, bright sunshine duration and the maximum possible sunshine duration (daylenght) data were abtained from the Kho Hong agrometeorological station, located about 18 km northwest of the study site.

1.5 Radiation data

The incoming solar radiative energy in the visible and near-visible wavelength bands was calculated using the actually measured and the maximum possible sunshine duration (daylength).

The relation is given by $R_i = [a+b*n/N]\ R_a$

where constant a = 0.25 b = 0.50

R_a = the theoretical maximum radiation at the top of the atmosphere

R_i = incoming shortwave radiation

n = bright sunshine duration

N = daylength

1.6 Air temperature data

Air temperature data were supplied by the meteo-station at Hat Yai air port, which lies about 12 km north from the study site.

1.7 Data analysis

The data analysis consists of two activites : The computation of the Net Primary Production (NPP) and the determination of the best linear relationship between the NPP and the measured environmental factors. Net primary production was estimated by summing changes in biomass and subtracting the losses through decomposition. The relation in formula form is :

$$NPP = \Delta W + Losses$$

where NPP = net primary production

ΔW = the difference of biomass over the harvest interval (changes in biomass)

Losses = Losses by decomposition

The relationship between NPP and environmental factors was computed by using the multivariate linear discriminant analysis of the SPSS package program.

Ninety six cases were taken from the monthly harvests of this present study and the parallel UNEP project on the same area.

2. Description of the study site and the climatic parameters

2.1 Location of the study site

The study site selected lies in the natural grasslands at Ban Klong Hoi Khong village, some20 km south west of Prince of Songkla University,on the eastern side of the south Thailand peninsular at about 6° 50' N and 100° 20'E.Its altitude is about 100 m above sea level.

2.2 Vegetations

The area is almost completely covered with a natural vegetation , consisting of grassland with scattered trees, and can be considered as savanna in the humid tropics. The grass vegetation is a composition of four main species catagories. There are: *Eulalia trispicata*, *Lophopogon intermedius*, *Fimbristylis tristachya*, *Dillenia hookeri* and other species. The proportion of apecies composition is presented in Appendix 4 and 7.

2.3 Soil

The soil type is classified in Visai series with low humic gley, which parent material is old alluvium. The land form pattern is low terraced with a 2 % slope, and poorly drained. During rainy season water logging occurs, which may last 3-4 months. In the dry period the water table can drop to 4 m below the surface.

The soil analysis showed that it has serious deficiencies in nutrient elements needed for plant growth, particularly phosphorus and nitrogen. The acidity is characterized by a pH of 4.4-4.5 at a depth of 30 cm (Kamnalrut and Evenson, 1985). More details on the soil characters are presented in the appendix 1 and 2.

2.4 Climate

2.4.1 Rainfall and evapo-transpiration

The climate of the southern peninsular Thailand is characterized as tropical monsoon climate with a binomial rainfall distribution due mainly to the influence of two seasonal monsoons, the south-western monsoon during May-September with a major peak in May, and the north-eastern monsoon during October-January with a major peak in November. The driest period of the year is fall usually in February- April, in which rainfall is less than 100 mm per month. The annual rainfall and the duration of the rainy season on the east coast and on the west coast is not exactly the same.

The length of the rainy season in Songkhla Province, along the east coast, has been analyzed by Apakupakul (1985). He showed that the duration of rainy season is 9.1 months (late April-late January) with the really humid period during September to January. The remaining three months (beginning February - mid April) cover the dry period of the year.

It is generally assumed that the rainy season begins when normal rainfall equals or exceeds half the potential evapo-transpiration, whereas the end is reached when normal rainfall was less than the potential evapo-transpiration. During the 1990-1991 period the amount of rainfall at the study site was measured and the potential evapo-transpiration (PET) was estimated. The data is shown in Figure 1.

2.4.2 Air temperature

The daily average air temperature varies just a few degree throughout the year, namely from 26.0 °C to 28.7 °C. The minimum temperature (at night) never drops below 20.7 °C, and the maximum temperature measured is 34.5 °C. From the measured temperature values, the maximum value of each day was selected and an average "max" was computed for each month. The same was done for the minimum(min) value of each day. In addition, the average temperature(determined from hourly measurements) of each day was again averaged over a month for each of the twelve months. The results are shown in Figure 2. As the growth of vegetation is optimal only in a limited temperature range, the data of Figure 2 should be used to determine this range for those months in which the other conditions are favourable for plant growth. The range is largest(12-6 °C) for February, and smallest (7-9 °C) for December. As the monthly average of the daily averages is only fluctuating 1.5 °C around the mean (27.5 °C), the range from maximum to minimum temperature is a useful parameter. Monthly maximum range of 12.6 °C occured in February, a minimum range of 7.9 °C recorded in December as shown in Figure 2.

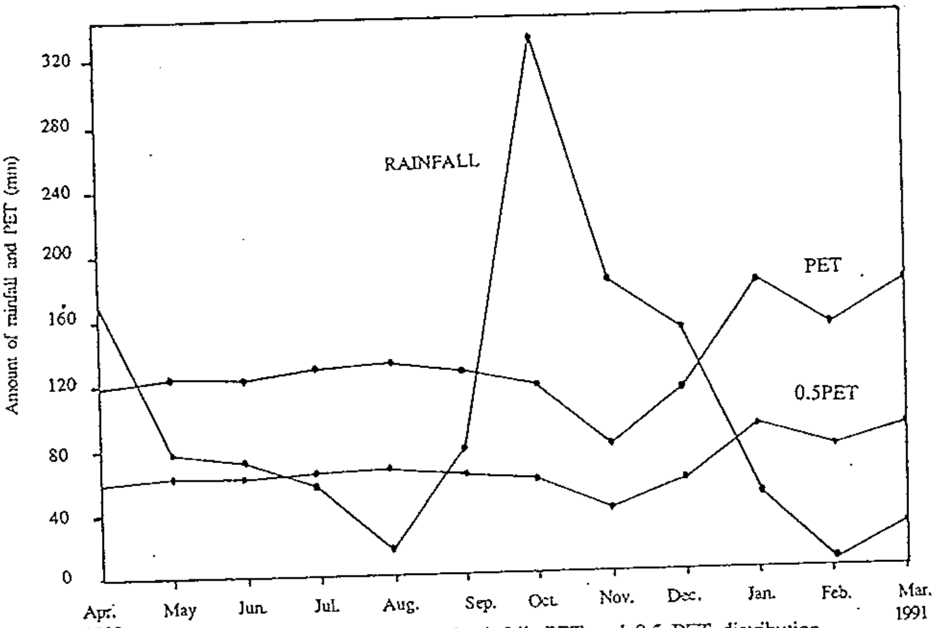

Figure 1. The monthly amount of rainfall, PET and 0.5 PET distribution during the period of investigation.

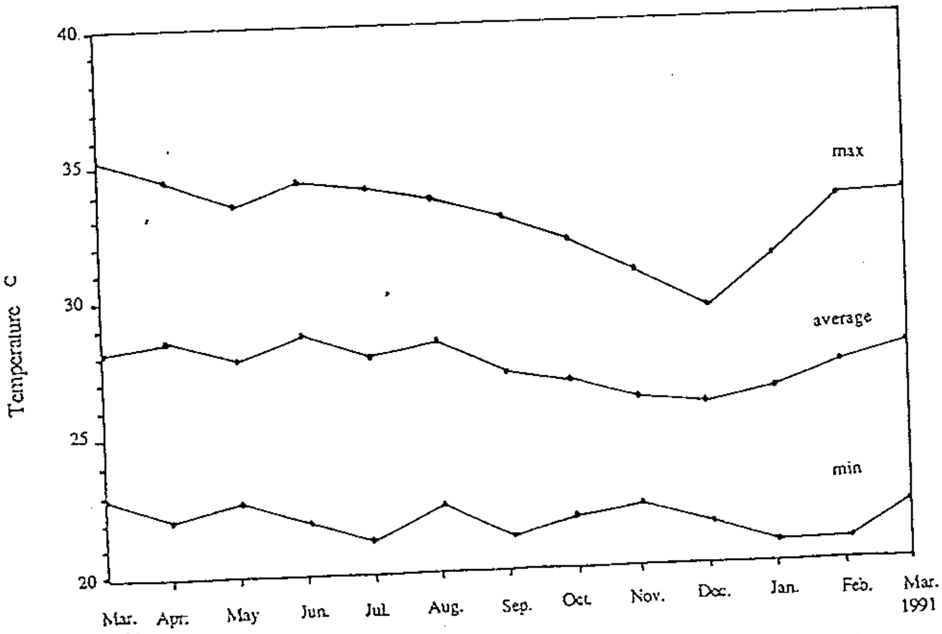

Figure 2. The monthly maximum, minimum and the average temperature during the period of investigation.

2.4.3 Solar radiation energy

Calculated solar radiation shown that incident light varied monthly from 339.27 cal.cm^{-2}.day^{-1} (in October) to 538.02 cal.cm^{-2}.day^{-1} (in February) as shown on Figure 3.

2.4.4 Daylength and duration of sunshine

The daylength during the study period varied little. The difference from the shortest daylength in December (11.7 hours and the longest daylength in June (12.5 hours) was only 48 minutes.

The minimum value of sunshine duration due to the presence of clounds was only 4.1 hours in September while the maximum value occured in February 9.3 hours as shown in Figure 4.

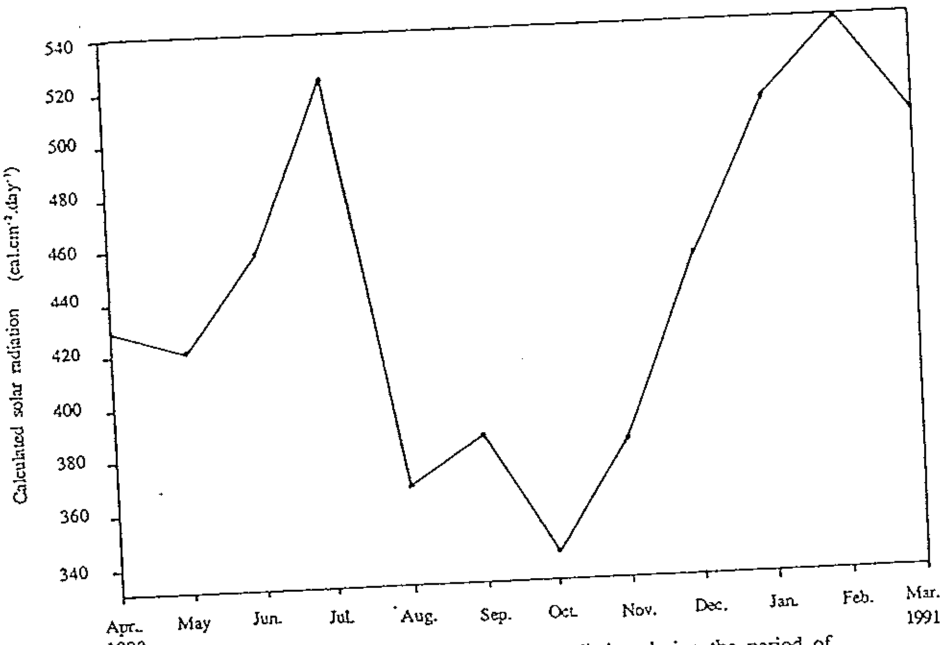

Figure 3. The monthly calculated solar radiation during the period of investigation.

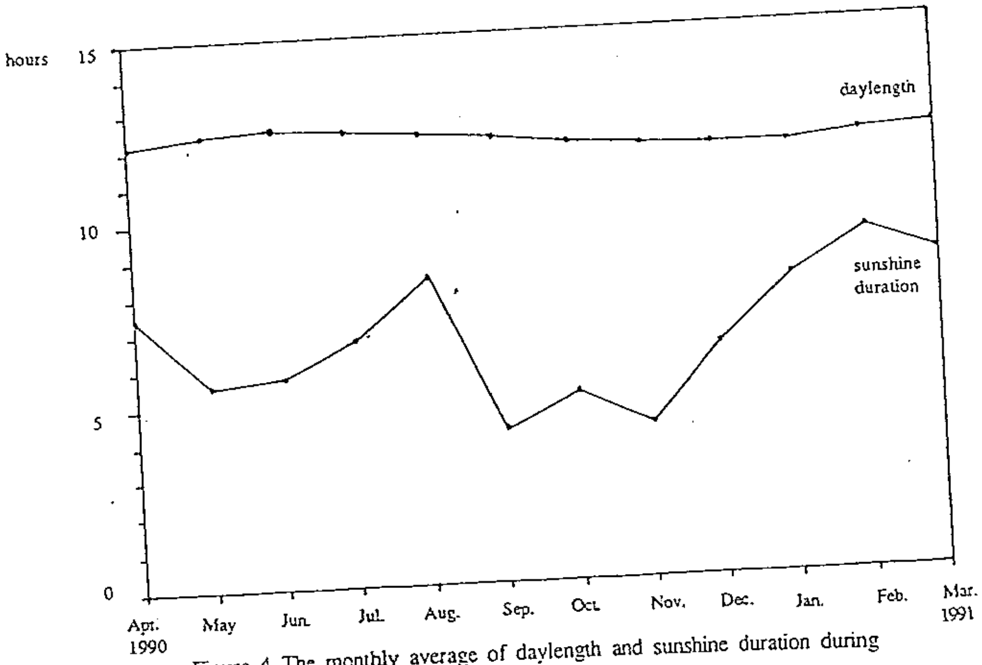

Figure 4. The monthly average of daylength and sunshine duration during the period of investigation.

CHAPTER 3

RESULTS AND DISCUSSION

1. Biomass dynamics

1.1 Variation of the above and below ground live biomass and dead matter in unburnt plot

Dry weight of the live above and below ground biomass and their respective dead matter in the unburnt plot is presented in Figure 5.

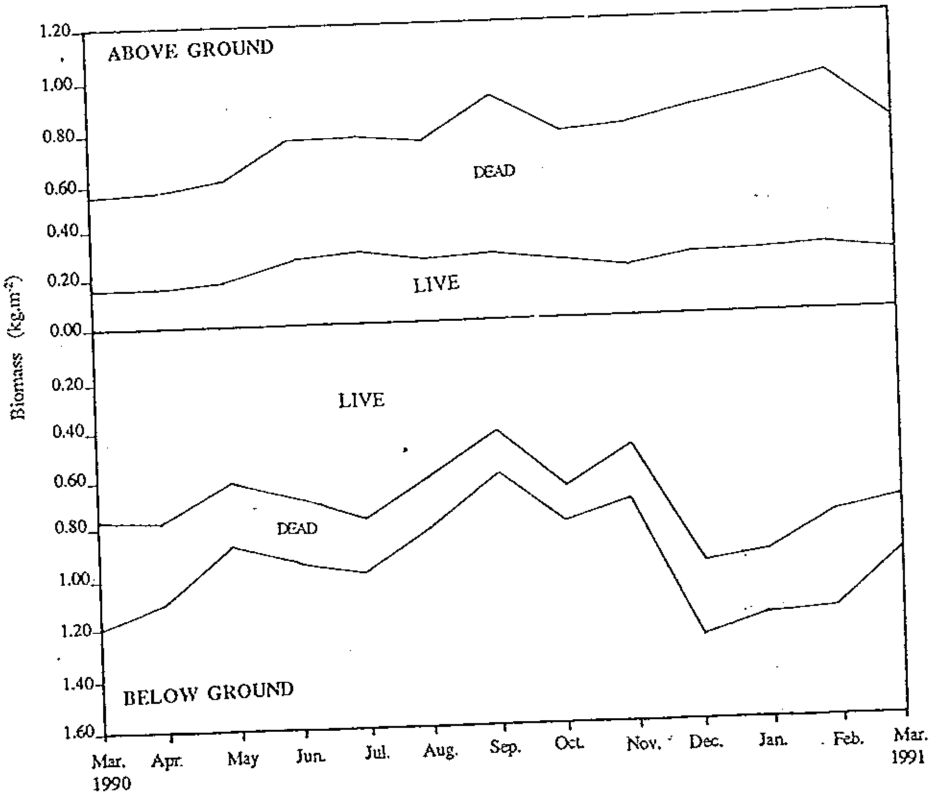

Figure 5 Monthly means of above and below ground live biomass and dead Vegetation of unburnt plot during the year of investigation, March 1990-March 1991.

1.1.1 Above-ground biomass

The monthly live above-ground biomass had the maximum and minimum value of 285.46 g.m^{-2} in July and 161.45 g.m^{-2} in April, respectively (Figure 5 and Appendix3), the range of which was not considerably differed throughout the investigation period, whereas the standing dead matter did increasing. The dead vegetation reached 2 peaks to be 634.46 g.m^{-2} in September 1990 and 700.85 g.m^{-2} in February 1991. They coincided with the dry period of the year and consequently contributed to the highest total above-ground dry matter (905.86g.m^{-2} in September and 979.71 g.m^{-2} in February). It is remarkable that the dead matter over a year period amounted to 2.30 time more than the live biomass i.e. the everage dead matter was 541.75 g.m^{-2} while the live biomass was only 235.82 g. m^{-2}. It is anticipated that the large portion of dead matter if there was no fire disturbance, may accumulate and was probably easy to be regulated by fire incidence (Kamnalrut and Evenson, 1992). Considering the live biomass of the four species catagories, the dominant species catagory 1, E.<u>trispicata</u>, contributed over 60% of the total biomass production while other species in species category 4 ranked second to the highest to be about 20% (Appendix 4).

It was observed that during the rainy period (October- December), density and number of species were at their greatest. As postulated by Singh (1969) that thismight be induced through decreased light intensities in closed canopy, therefore resulting no significant increase in live biomass as found in this study. The dead matter which increased in the dry period was also commonly found in other grassland ecosystems by several authors (Kuldilok, 1983).

1.1.2 Below-ground biomass

The below-ground part of the vegetation varied much more in higher degree than its above-ground portion (Figure 5 and Appendix 5). The range between maximum and minimum of the live biomass was 1015.55 g.m^{-2} in December 1990 to 458.88 g.m^{-2} in September 1990 and found to be inconsistent with it's corresponding above-ground biomass. The trend showed that it had the rapid growth in humid season especially in December which was after the peak of rainy season. The dead matter of the below-ground part varied in parallel with its corresponding live part. Contrasting to the above ground, the live below ground biomass produced more than the dead matter which was found to be about 3 times. The most density of below ground mass was as much as 68% of the total and found to be within the 1-10 cm depth. This confirmed the statement made by Lammotte (1967) that different types of savanna appeared to be broadly semilar in root distribution within soil depth. The root density found in Indian grasslands, however, was found most within 10-30 cm depth of which the pattern of root extension and stratification was attributable to the wet and dry phases of the specific habitats (Raman, 1970).

1.2 Variation of biomass in burnt plot

1.2.1 Above-ground biomass

The growth of new shoots or live biomass increased simultaneously after burning from March to October 1990 and then maintained its steady growth state to February 1991. It decreased slightly at the last harvest of March (Figure 6 and appendix 6). The sward resumed its normal production as it was with unburnt plot approximately 6 months after burning i.e. to reach the value at about 200 g.m^{-2}.

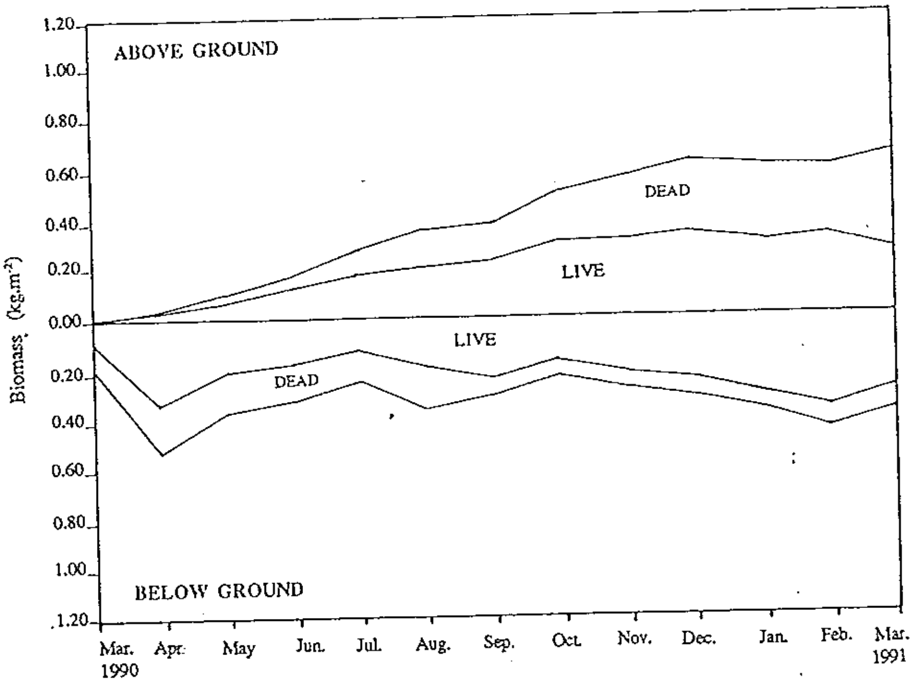

Figure 6 Monthly means of above and below ground live biomass and dead vegetation of burnt plot during the year of investigation, March 1990-March 1991.

The standing dead developed slowly during the 4 months after burning and thereafter accumulated at faster rate and being almost 50% apportioned to its live biomass production. It showed a trend that accumulation of dead matter was continuing over when its live biomass was at decreasing rate (Figure 6). However, within a period of one year, the standing dead matter could not attain the maximum value of the old sward i.e. maximum value of the new sword was 391.93 $g.m^{-2}$ in March 1991 as compared to 700.85 $g.m^{-2}$ of the old sward in February 1991 (Appendix 3 and Appendix 6). It is anticipated that if the new sward accumulated at the rate of the later stage, the standing dead might attain the maximum value equivalent to the old sward within the next 2-3 months.

From the previous studies, Kamnalrut and Evenson (1992) estimated above ground biomass of the same grass community when subjected to fire and found that biomass production varied accordingly to environmental factors especially rainfall. Moreover, different layers of vegetation in different months could vary considerably according to their light and water adaptation characteristics (Singh and Yadava, 1974). Therefore, in comparison with the present study, temporal variation in attaining peak biomass with different quantity could not be expected to follow the same pattern even with the same grass community. The only pattern observed to be similar with the previous study is that the biomass increased simulteneously at a higher rate just after fire incident, though differed in different year and there after the rate decreased when approaching the peak biomass. The composition of the new sward community constituted from the 4 species catagories was almost the same proportion as the old sward namely about 57% from the species catagory 1, E.trispicata and about 20% from other species category 4 (Appendix 4 compared to Appendix 7). This would imply that the grass community in both cases were quite uniform in their composition, even when the sward had been subjected to fire. This confirms also the previous study and may indicate that this grass community has an ability to survive over other different species in normal and adversed environmental conditions i.e. fire incidence in this case. Though it is interesting, it is difficult to point out any possible mechanism reposible for such special kindof adaptive response through this present study. It may be possible that its perennating habit with large buried crown may play a significant role in expressing that phenomena as stated by Humphreys (1981).

1.2.2 Below-ground biomass

The below ground biomass in burnt plot varied from a minimum value of 121.54 $g.m^{-2}$ in July 1990 to a maximum value of 361.92 $g.m^{-2}$ in February 1991 (Appendix 8). The amount of dead matter produced varied at the earlier stage and produced less relatively varied at the earlier stage and produced less relatively constant rate after 6 months of regrowth establishment (Figure 6). The everage proportion of dead to live was 0.43 which was not much differed from the ratio of the unburnt plot. The total mass (live and dead), however, produced under the burnt condition was far less than the amount of the unburnt one (comparison the average values in Appendix 5 and Appendix 8).

Comparison with the previous study (Kamnalrut and Evenson, 1992), similar results that root biomass estimation after fire incident decreased proportionaltely to its shoot biomass. This is to assure an explanation that the regrowth of new shoots after burning was at the expense of below-ground portion i.e. there was a translocation process taken place from root to shoot. The ratio may vary from year to year depending upon the environmental variables. The root mass happened to be more depleted when successive burning of the same grass community occured (Kamnalrut and Evenson, 1992).

1.3 The variation of total biomass

Total biomass is refered to the sum of the live and dead matter above and below ground. Figure 7 shows the pattern of total biomass both from unburnt and burnt plots. It is obvious that the cases of the two different swards shows remarkably different patterns of accumulating the total biomass. The unburnt plot displays its variation throughout the year seems to be dependable on environmental variables whereas the burnt plot is simulteneously on its course of ontogenic developmental process. The total above ground biomass of old unburnt sward is closely correlated with the dead matter than live biomass (r=0.96 and 0.78 respectively, Table 1), whereas total below ground biomass is highly

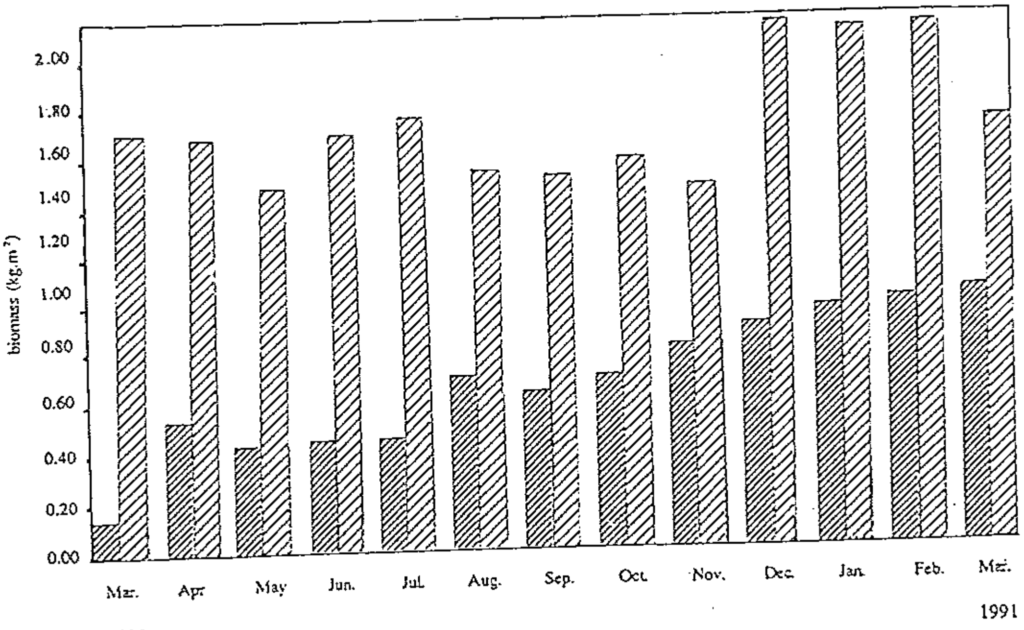

Figure 7. The total biomass in unburnt plot (▨) and burnt plot (▨)

correlated with live below ground biomass than below ground dead matter(r = 0.96 and 0.75 respectively, Table 1). In burnt plot, the total above ground biomass is highly correlated with above ground live and above ground dead matter (r=.96 , Table 2). It is also noticeable that the dead root is significantly negative correlated with the live above ground biomass and the total above ground biomass (r = -0.84 and -0.77, respectively, Table 2). This indicates the relationship as mentioned previously that the regrowth of new shoots after burning was at the expense of below ground live biomass reflecting less amount of dead below ground matter being produced.

Table 1. Simple correlation matrix for live and dead components of biomass in unburnt plot.

	Live above	Dead above	Total above	Live below	Dead below	Total below
Live above	1.0000					
Dead above	.5836	1.0000				
Total above	.7778*	.9643*	1.0000			
Live below	.1666	.1641	.1813	1.0000		
Dead below	-.0064	.1145	.0865	.5414	1.0000	
Total below	.1287	.1661	.1806	.9615*	.7515*	1.0000

Remark: 2-tailed Signif.: *-.001

Table 2. Simple correlation matrix for live and dead components of biomass in burnt plot.

	Live above	Dead above	Total above	Live below	Dead below	Total below
Live above	1.0000					
Dead above	.8618*	1.0000				
Total above	.9601*	.9692*	1.0000			
Live below	.0830	.3298	.2220	1.0000		
Dead below	-.8371*	-.6685	-.7746*	.0412	1.0000	
Total below	.1252	.5489	.3632	.2442	-.0966	1.0000

Remark: 2-tailed Signif.: *-.001

The total biomass seperated into the above and below ground in both plots are presented in Figure 8 and Figure 9. The shoot root ratio in burnt plot, in average, was higher than the unburnt one to confirm again the above statement. Long, et al. (1992) postulated that in perennial grassland underground or surface storage organs significantly transfer of assimilate between above and below ground components. In stress conditions e.g. dry or cold seasons, translocation of matter from shoots to below ground storage organs can occur. During that period, the above ground biomass will decline and below ground biomass rise. This is the case with the unburnt and burnt plots of which the ratios are low during the dry period of April and May.

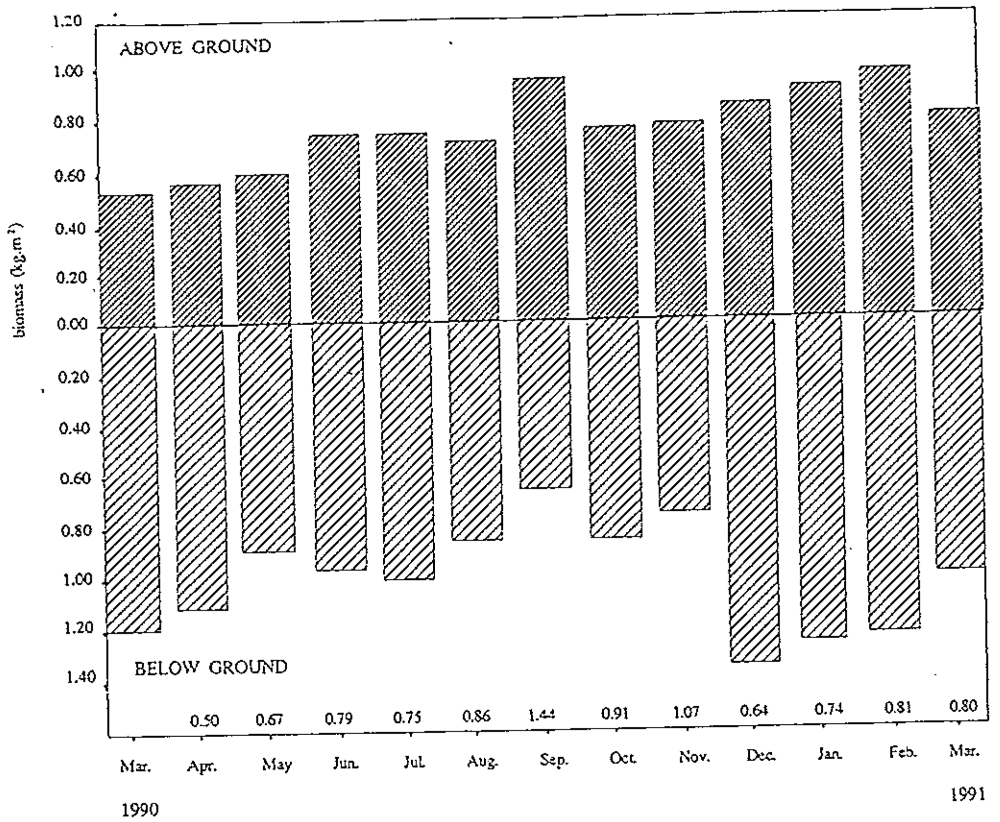

Figure 8. The total above and below ground biomass and dead vegetation in unburnt plot, figure at the bottom are the values of shoot/root ratio.

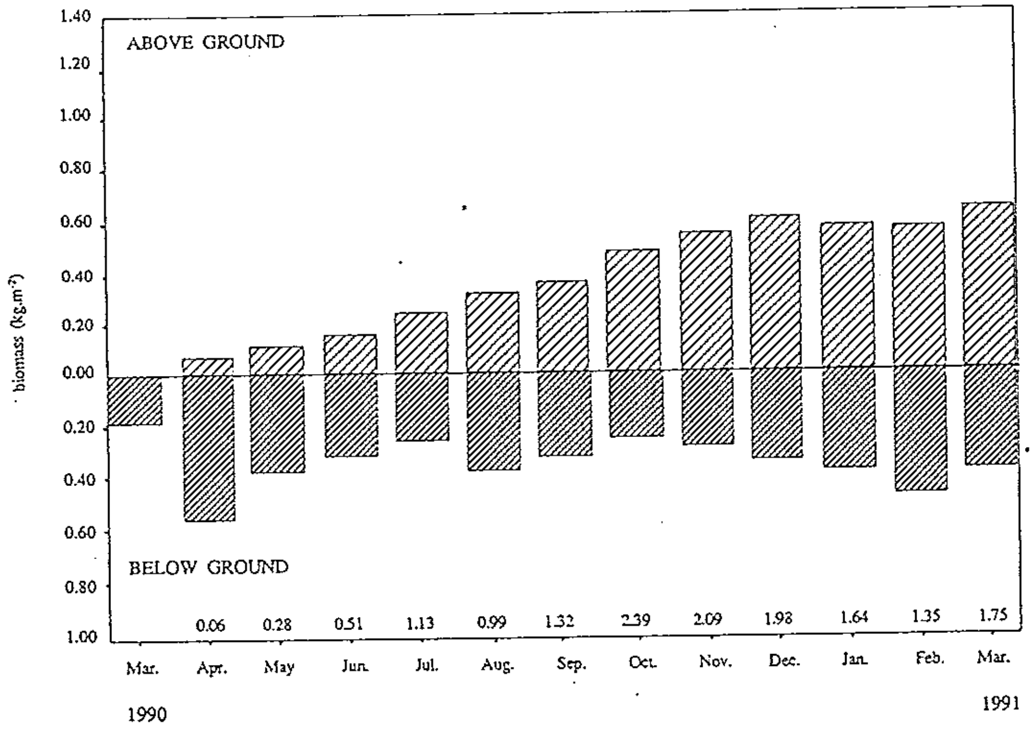

Figure 9. The total above and below ground biomass and dead vegetation in burnt plot, figure at the bottom are the values of shoot/root ratio.

1.4 Decomposition

The litter bag technique was used to determine the rate of decomposition both of below and above ground. The results are shown in Figure 10. The relative rate of decomposition of both unburnt and burnt plot, in general showed the same trend in response to periodic changes of environmental factors, although inconsistent amount of decomposition at the three positions namely in the canopy,on the ground level and underground were observed. In average, the high decomposition rate between 0.20-0.35 $g.g^{-1}.month^{-1}$ commonly found during the months April-May, July-September and March. The slowest rate below than 0.10 $g.g^{-1}.month^{-1}$ was found in the month of June and November. The overall average value of the decomposition rate was 0.2 $g. g^{-1}.month^{-1}$. The range of decomposition rate found in this study is closed to the value obtained from the provious studies (Kamnalrut and Evenson, 1992). The similar trends of decomposition rate of the unburnt and burnt grassland conditions reflected the characteristic of this grassland community in correspondance with external environmental factors. The hightest rates followed the period of dry season which atmospheric temperature is also high and canspeed up microbial activities in decomposing process leading to high rate of decomposition. This result is constrasting to the study in Indian grasslands of which Yadava and Singh (1977) found that decomposition rate was highest during rainy season. With a paucity of information, the results can

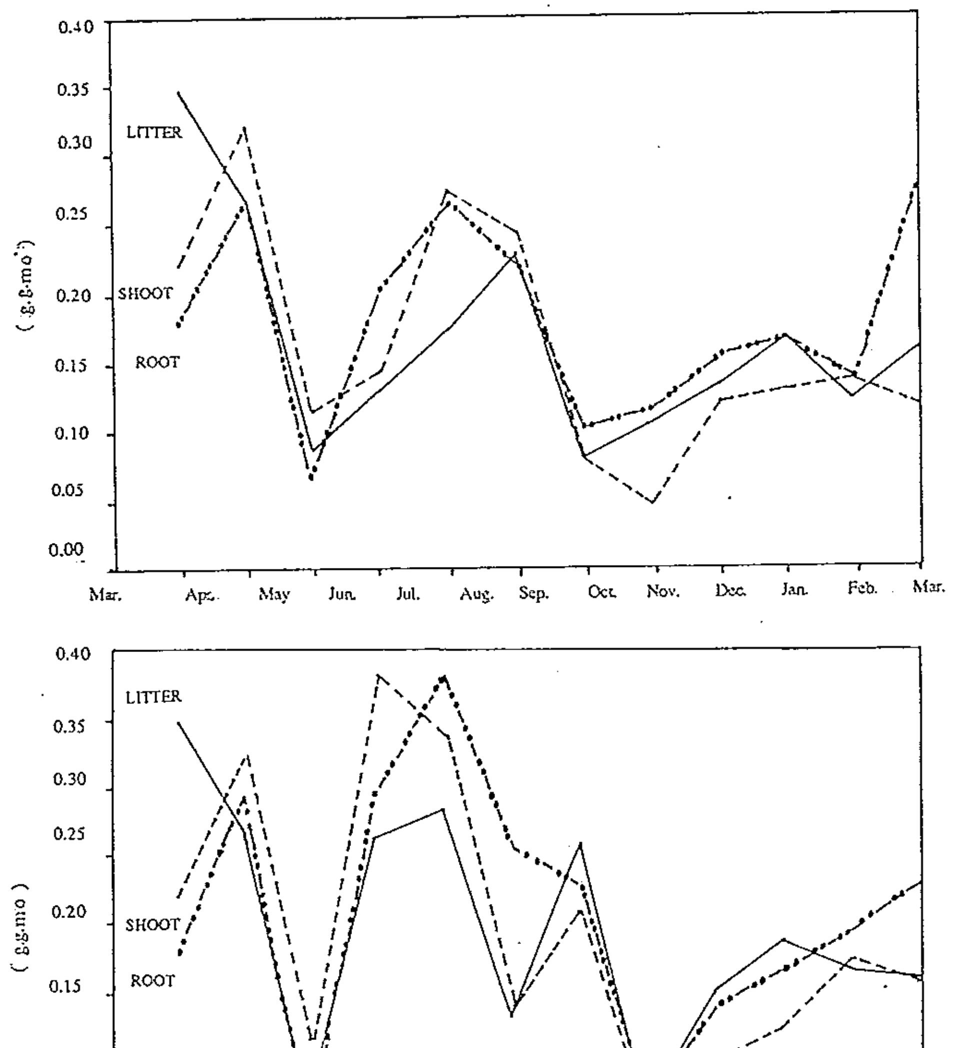

Figure 10. Monthly rate of decomposition of the unburnt (above) and burnt (below) plots within the canopy (shoot), at ground level (litter) and under ground (root).

not be intepreted well unless this quite complex process will be understood thourough studies will of plant-decomposers-environment interactions.

2. Net primary production

The monthly net primary production (NPP) computed from the sum of change in biomass and the loss through decomposition both below and above ground is shown in Appendix 9 and Appendix 10, respectively and the total net primary production which is the sum of below and above ground production is presented in Table3. According to net changes model by Long, et al. (1992), summarized partitioning and fate over the 12 months from April 1990 to March 1991 is shown in Figure 11.

The total annual net primary production in Figure 11 was obtained from the following procedure the total net primary production of the unburnt plot was 1453.13 $g.m^{-2}$(14.53 $ton.hectare^{-1}$) being obtained by summing the net primary production of the shoot (1244.90 $g.m^{-2}$ or 12.44 $ton.hectare^{-1}$) and root (208.23 $g.m^{-2}$ or 2.08 $ton.hectare^{-1}$) The net primary production of the shoot was obtained from the sum of net loss of the biomass change (47.52 $g.m^{-2}$), and the net amount of death (1197.38 $g.m^{-2}$). The amount of death vegetation was the sum of the net amount loss through dead vegetation change (175.74 $g.m^{-2}$) and the total amount of decomposition (1021.64 $g.m^{-2}$). The below ground net primary production (208.23 $g.m^{-2}$) was obtained in the same manner as the above ground shoot primary production.

Table 3. The monthly and total net primary production ($g.m^{-2}.month^{-1}$) of unburnt and burnt plots partitioned into above and below ground.

	Unburnt NPP			Burnt NPP		
	Above	Below	Total	Above	Below	Total
1.Apr.	104.31	-13.56	90.75	33.13	394.32	427.45
2.May	169.83	-155.37	14.46	80.81	-129.02	-48.21
3.Jun.	210.53	80.57	291.10	65.22	-28.04	37.18
4.Jul.	64.05	74.67	138.72	128.34	-56.65	71.69
5.Aug.	109.18	-130.23	-21.05	138.29	185.18	323.47
6.Sep.	332.19	-174.18	158.01	58.22	-59.77	-1.55
7.Oct.	-101.05	222.29	121.24	175.36	-58.39	116.97
8.Nov.	46.54	-88.32	-41.78	67.50	59.55	127.05
9.Dec.	142.85	633.03	775.88	93.89	59.01	152.90
10.Jan.	132.93	-65.56	67.37	13.73	59.85	73.57
11.Feb.	170.46	26.91	197.37	43.46	93.21	136.67
12.Mar.	-136.92	-202.02	-338.94	122.77	-46.67	76.10
Total	1244.90	208.23	1453.13	1020.72	472.58	1493.29

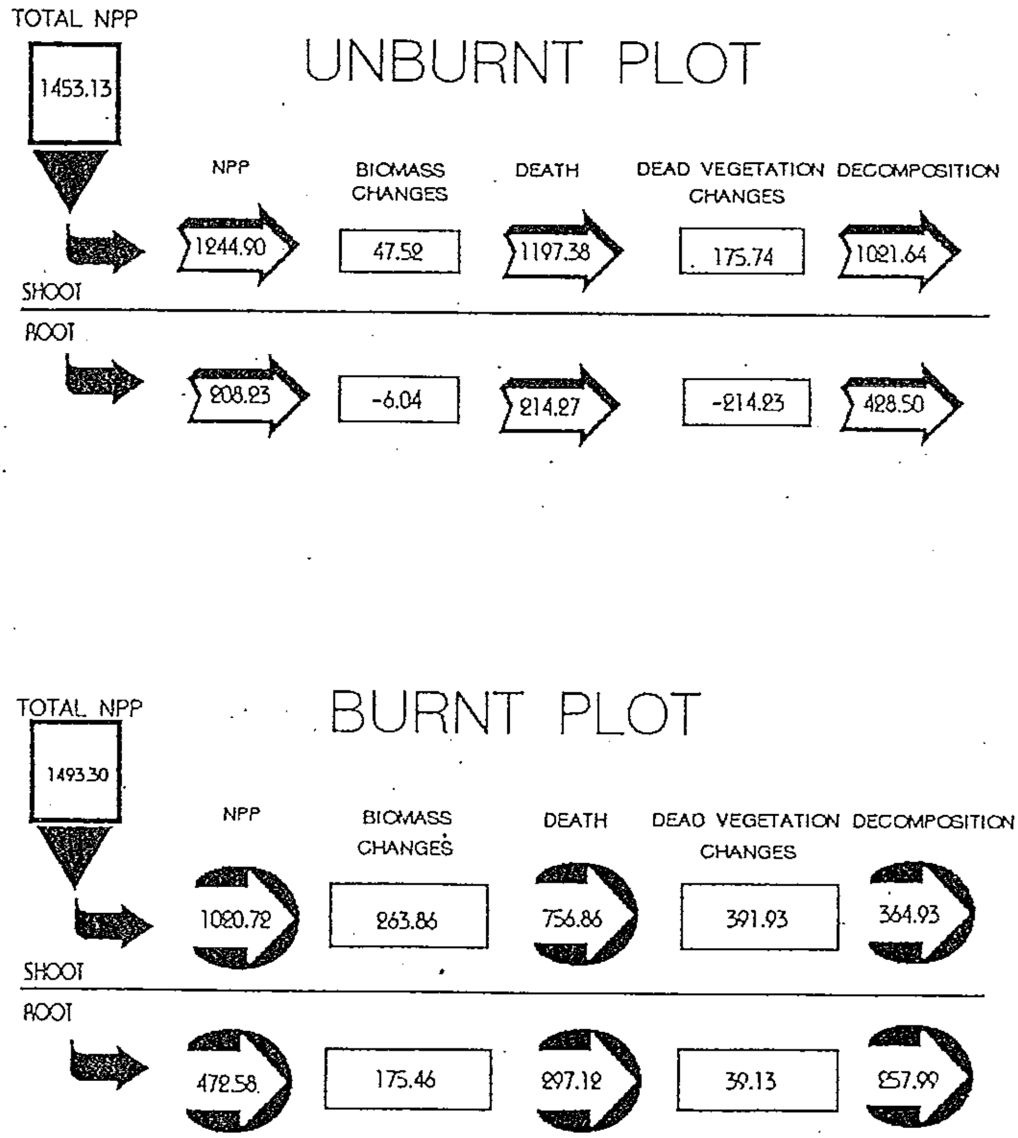

FIGURE 11. Summarized partitioning of the net primary production (NPP) of the both burnt and unburnt plots. The sum of biomass changes are presented by rectangulars and the arrowed boxes illustrated fluxes.

In the burnt plot (Figure 11), the total annual net primary production was found to be 1493.30 $g.m^{-2}$ (14.93 $ton.hectare^{-2}$) which was partitioned into shoot net primary production 1020.72 $g.m^{-2}$ and root net primary production, 472.58 $g.m^{-2}$.

The results showed that the total net primary production of the grassland subjected to unburnt and burnt conditions gave an approximately the same figure. This will mean that the annual rate production of biomass of this grassland was kept unchanged regardless of unburnt and burnt conditions. There were, however, different partitioning of the above and below ground net primary production in both situations.

The relative distribution between shoot and root is about 85% and 68% for unburnt and burnt plot, respectively. While total NPP is produced in similar quantity from both unburnt and burnt plots. The change in biomass into dead matter occurs much higher in unburnt than burnt area. The dead matter, subsequently, is decomposed at higher rate than quantity in burnt plot. It can be seen from this result that when the sward is subjected to fire, several consequences can occur: Firstly the new regrowth grass community will speed up its production rate and being at equal rate with the old unburnt plot within one year. Secondly, the new grass sward produces more young active tissues both in shoot and root organs and being more efficient in assimilation whereas the old unburnt sward produces more on dead matter than live biomass. Thirdly, as a consequence, decomposition of dead matter is high in unburnt sward, hence, higher turn over rate of organic matter into the sward community is expected.

As it is only a one year cycle of production, it cannot be seen at the present time that an impact of fire can change or alter this grassland ecosystem. Consideration from the previous studies (Kamnalrut and Evenson, 1987, 1992) and the present study, this grass community has not changed so much in terms of species composition after recovering from fire incidence. It exhibits its capacity to tolerate fire and featuring this savanna grassland type. The most likely that this moist savanna servives after fire incidence, as pointed out by Frost (1984), to be due to the ability to resist fire by having vital tissues insulated from high temperatures, and the capacity to recover vegetatively when fire damages plant tissues. Usually fire occurs during the dry period of the year (February, March and April) at the interval of 1-3 years. During that time the plant community also experiences water stress which can stimulate buds of the burried crown to be dormant. As postulated by Frost (1984), fire will break the apical dominance of the dormant buds and thereafter differentiates new shoots sprouting from underground crown.

3. Net primary production and environmental variables relationships

The variation of the net primary production as discussed in the previous section shown to be dependent on its environmental factors.In this study,it was assumed that climatic elements will be the determinant factors influencing the variation of the net primary production. The environmental factors chosen in this study are of those monthly rainfall, potential evapotranspiration (PET), air temperature, solar radiation, daylength and duration of sunshine. The patterns of these climatic factors over a year of investigation and their relationships among each other are shown in Figure 1, Figure 2, Figure 3 and Figure 4.

Considering the net primary production in each month, the variation consisted of both increasing and decreasing rate of production. Among the whole 96 samples of both from unburnt and burnt plots throughout the year, 67 samples were found to be at increasing rate (positive values) and the rest 29 samples were at decreasing rate (negative values). The stepwise multivariate linear discriminant analysis was applied to find out which environmental factors influencing or governing the discriminant increasing and decreasing rate of production as described in the following:

3.1 Group means of explanatory (independent)variables

The decreasing rate or negative net primary production was designated as group 1 and the increasing rate of positive net primary production as group 2. The environmental factors or explanatory variables of which their means and corresponding standard deviation fall into the groups and all group as a whole are presented in Table 4.

Table 4. Means and standard deviation of each environmental factor as explanatory variables classified into two groups, negative (Group 1), positive (Group 2)NPP and the total (All group).

Explanatory variables	Group 1 $\bar{X}$	SD.	Group 2 $\bar{X}$	SD.	All group $\bar{X}$	SD.
1.Precipitat^{n}	76.84	70.37	110.44	95.82	100.29	89.88
2.PET	36.48	30.44	128.34	24.65	130.80	26.64
3.Radiation	448.14	69.10	438.53	61.59	441.42	63.73
4.Daylength	12.10	0.24	12.06	0.28	12.07	0.27
5.Sunshine duration	6.59	1.85	6.65	1.61	6.63	1.67
6.Air-temperature	22.03	0.77	21.75	0.67	21.84	0.71

The results showed that the mean of individual predictor variable defined into two groups had, excepted for precipitation which varied most, only slightly difference. This table gave the general view of the nature of individual input data when classified into the two groups.

3.2 Selecting factors into the discriminant function

The procedure of analysis proceeded further to select the independent variables which were eligible for inclusion in the computation as predictor variable. The factor(s) which contained no significant information or cannot define the groups when combined with other variables would be not selected into the analysis. As a result, radiation and daylength were the two variables not included in the analysis. The variables selected into the discriminant function were, therefore, those temperature, precipitation, PET and duration of sunshine. The group means of these variables as per individual and combination were statistical tested for their difference. Table 5 summarized some of results of the testing. Significant difference at the probability level of 0.0179 was found to be with the combination variables of temperature, precipitation, PET and duration of sunshine in the step 4 of the analysis. This was also indicated by the lowest Wilk's lambda or U statistic (0.8784) as compared to other variables (value closed to 0 indicated the higher degree of difference between the group means).

Table 5. Summary of Wilk'slambda values and significant testing of different variable combination.

Step ng	Variables	Wilks' lambda	F	Degree of freedom		Sig.
1.	Temperature	.9692	2.9862	1	94	.0873
2.	Precipitation	.9252	3.7594	2	93	.0269
3.	PET	.9144	2.8701	3	92	.0407
4.	Sunshine durat^{n}	.8784	3.1494	4	91	.0179

3.3 The discriminant equation and the score

The combined four variables as a parameter was found to be the best in defining the difference among the two group means as mentioned in the previous section. In discriminant analysis , a linear combination of the independent variables was formed and served as the basis for assigning cases or factors to groups. The information contained in this multiple independent variables, by the process of analysis, would be summarized into a score as a single index. The score were calculated from the linear discriminant equation which was similar to the linear multiple regression equation. The coefficients of each variables concerned in the equation together with their standardized coefficients are presented in Table 6.

Table 6. The standardized and unstandardized coefficient for variables in the discriminant function.

Variables	Unstandardized coefficient	Standardized coefficient
Precipitation	-.0065	-.5835
PET	.0359	.9540
Duration of sunshine	-.5348	-.9029
Temperature	.9450	.6675
Constant	-21.1422	

The unstandardized coefficients are formed a linear discriminant equation which will be used to calculate the discriminant score for each case. The equation is as follow:

$$D = .0359\ P - .5348\ S + .9450\ T - .0065\ R - 21.1422$$

where D = Discriminant score
P = Potential evapotranspiration
S = Sunshine duration
T = Minimum air temperature
R = Precipitation (rainfall)

The standardized coefficients will form a basis of comparison of the relative importance among variables entered in the function. As shown in Table 5, potential evapo-transpiration had the largest value standardized coefficient indicating that this variable was the most important predictorin the function. However, this value has been derived from the analysis of combined variables. Therefore, its relative importance has to be considered together with other factors.

As in multiple regression, the discriminant score were calculated from the discriminant function by using variables in the original unit. The score for the mean values of each variable in both group in Table 4 were defined as group means or group centriod. The results show that the discriminant score is larger in group 1 than in group 2 indicating that larger score tends to have high probability of decreasing NPP (group1) or negative group as shown in Table 7.

Table 7. Group means or group centroids for the two group.

Group	Group means
Group 1(Negative NPP, decreasing biomass)	0.5596
Group 2(Positive NPP, increasing biomass)	-0.2422

3.4 The effectiveness of the function

The effectiveness of the function can be examined through the statistics resulted from the statistical analysis shown in Table 8.

Table 8. The statistics resulted from the analysis of the discriminant function.

Eigen value	0.1384
Canonical correlation	0.3487
Wilk's lambda	0.8784
Degree of freedom	4
Singnificance	0.0179

The low eigen value (the proportion of group sum of square to within group sum of square) of 0.1384 indicated that there was much variation within the group than between groups or other word the two group means were not much differed from each other and the variation wihtin group was high. This was also indicated by the high Wilk's lambda value (the ratio of the within group sum of square to the total sum of square) of 0.8784. Consequently, it gave a relative low canonical correlation (degree of association between discriminant scores and the groups measured by the square root of the ratio between group sum of square to the total sum of square) of 0.3487. However, the group means were significantly different at P<0.0179. The interpretation from these statistics, therefore, was that function can significantly classify between the group means eventhough the two group means have not much different values from each other and within group means have considerably variation.

3.5 The results of classification

Based on the observed proportion of cases falling into each group and the Bayes's rule, an estimate of prior probability of 0.30 is obtained for the group 1 (decreasing NPP) which means 30% of cases belonged to group 1 and 70% of cases belonged to group 2 (increasing NPP). Table 9 presents the correct and incorrect classification of each group calculated from the actual counting cases and predicted cases derived from the discriminant function.

The results show that the prediction of group 1 membership by the function is not good with the case of decreasing effect of NPP. On the contrary, the increasing NPP of the group 2 is able to be correctly predicted by the function as high as 91%. The overall precentage of cases correctly classified is calculated to be 73.96%.

Table 9. The results of classification of the two groups accounting for correct and incorrect classification.

Actual group	Number of actual cases	predicted group (group 1)	membership (group 2)
group 1 (decreasing NPP)	29	10 (34.50%)	19 (65.50%)
group 2 (increasing NPP)	67	6 (9.0%)	61 (91.0%)
percent of cases classified correctly		73.96%	

3.6 The predicting variables

The explanatory variables being included in the discriminant function equation are potential evapo-transpiration(PET) duration of sunshine , temperature and precipitation (Table 6). These factors will determine whether the primary production produced in a given time fall into negative group 1 (decreasing rate) or positive group 2 (increasing rate). Their degrees of importance are indicated by their corresponding standardized coefficients presented in Table 6 are described as follows:

3.6.1 Potential evapo-transpiration (PET)

This factor had largest standardized coefficient of 0.96 (Table 6) which means that the score calculated from the equation has the closest relation with the PET variable. The unstandardized coefficient value of 0.0359 of the equation established the linear relationship between the score and the PET value i.e. an increase in 1 unit of PET will increase 0.0359 unit of score or other word a larger in 1 unit of score will be as a result of an increase in 27.86 unit(mm) of PET (1/0.0359). This can be interpreted that PET is the most important factor involved in the discriminant function. The higher PET is the larger discriminant score and the larger discriminant score gave the higher probability of NPP to be belonged to the negative group 1 or at decreasing rate of production. This may be due to the fact that the higher PET will induce higher plant water stress especially at less precipitation.

There are quite a few literatures established the relationship between PET and NPP, though evapo-transpiration has been reported to influence the drymatter production(Stanhill, 1960: quoted in Doorenbos, 1977: 61). Rosenzweig (1968), on the other hand, has found that actual evapo-transpiration rather than potential evapo-transpiration (PET) influenced the above ground biomass production on a worldwide scale while Lieth and Box (1972) suggested that the world NPP could examined through rainfall, actual and potential evapo-transpiration. In fact, PET is such a climatic parameter associated with plant cover characteristic and under other two governing factors, water availability in the soil and an evaporative demand (Dastane, 1974). Evaporative demand is again dependable on temperature mathematically derived. It is, therefore, a reason to believe that PET in itself could represent as an integration of climatic and plant factors and being the most important factor in discriminating the positive and negative NPP.

3.6.2 Duration of sunshine

The standardized coefficient of the duration of sunshine is -0.90, the largest value second to the coefficient of the PET. Its negative value indicates the negative correlation between the value of duration of sunshine and the discriminant score. The unstandardized coefficient of -.5348 (Table 6), indicates the linear relationship that by increasing duration of sunshine was 1.87 hours (1/.5348) will decrease 1 unit of the discriminant score and brings about higher probability of the net primary production to be positive group 2 (increasing rate of production). It is logical to think that longer duration of sunshine will also prolong the radiation being utilized by plant, thus, producing more assimilates. Longer sunshine duration during driest months (January, February, March and August, Figure 1), though variably in magnitude, were found mostly to be at increasing NPP (Table 3). Variation in NPP in relation to sunshine duration might be due to interaction of this factor with other environmental variables. The interaction interms of sunshine duration with other factors to influence NPP has not been reported elsewhere. Radiation effect on plant production, instead, has been shown to be altered by other climatic factors for instance; Mc Crown (1981) attached little importance to low radiation during the monsoon seasons in the monsoon and tropical tallgrass savanna. Williams and Probert (1984) have demonstrated that low radiation during periods of favourable water and temperature environments can limit pasture production region west of Chartars Towers, but the importance of radiation constraints has not been examined elsewhere (Mott, et al., 1979). It is, therefore, the clear effect of sunshine duration on NPP in this study can not be interpreted as a single factor but has to be considered along with other environmental factors. This is to speculate , however, that the longer duration will prolong photosynthetic activities, hence increase production rate. The period of which sunshine duration in this investigation was higher than the lower limit of increasing rate (6.65 hours.day^{-1}, Table 4), was to be among the months of January, February, March and August (Figure 4). Those periods, except for August were concided with the time that PET was also higher than its upper limit of decreasing production rate (136.48 mm, Table 4 and Figure 1). These two factors, thus, counteracted each other in opposite directions to influence the magnitude of NPP to be positive or nagative.

3.6.3 Temperature

The air temperature has the positive value of standardized coefficient of 0.67 (Table 6). This means that air temperature correlates positively with the discriminant score. The unstandardized coefficient of 0.945 give the relationship between air temperature and the score that increase each of 1.06 °C will increase 1 unit of score (1/0.945 = 1.06) and the larger of discriminant score will increase probability of the NPP to be belonged to negative group 1 catagory. Temperature has been known to effect significantly metabolism of living organisms. The response of plant to temperature varies among species and is often closely related to enzyme activities. Higher and lower temperature than its optimum level will have detrimental effect on plant growth and development. It has been reported that winter temperature caused the tropical tall grass savanna in West Africa to reduce NPP (Mott, et al., 1985) while the report from UNESCO (1979) stated that high mean temperature increased considerably amount of respiration and reduced NPP of the tropical savanna. The result from this study indicates the importance of minimum temperature to be a lesser degree than PET and sunshine duration but its significant role on NPP is dipicted by the equation. The sensitivity of low temperature, especially occuring during the might in this savanna grass community may indicate that higher might temperature than its critical mean level (21.75 °C, Table 4) will reduce NPP. This is most probably due to higher respiration rate caused by elevating temperature as it was reported by UNESCO (1979).

3.6.4 Precipitation (rainfall)

The value of standardized coefficient of this variable is -0.58. Its negative value indicated the negative correlation between the precipitation and the discriminant score. The value of unstandardized coefficient of -0.0065 constitutes the relationship that an increase in rainfall amount of 153.85 mm will decrease 1 unit of the score (1/0.0065 = 153.85) and this brings about probability of NPP to be positive. Rainfall is the only main source of water supply for the growth and development of this grassland community. It was expected that production will be greatest in rainy season as it used to be indicated by several authors (Yadava and Singh, 1977; Singh, et al., 1985) while rainfall variable in this study is found to be the last important factor influencing the NPP. This controversial phenomena might not be crucial when it is considered along with the most important factor i.e. PET in the discriminant equation function since rainfall and PET are important input factors in balancing plant and soil water status. This finding implies the importance of PET in determining the rise and fall of NPP rather than rainfall in this particular grassland ecosystem. It is inclined to believe that the production will be at normal rate under this annual rainfall regime unless high PET occured, especially when PET exceeds rainfall in dry season inducing plant water stress. The production process will be then limited to a slower rate.

Based on the discriminant analysis, though PET was found to be the most important variable in predicting the rise and fall of the NPP it was noticeable that during the wet season of December when precipitation was the highest, the discriminant function could classify all of the cases correctly (Appendix 9). At this period of time, the differences between the maximum and minimum temperature was also minimal. Such conditions brought about better prediction of NPP than when precipitation was less and maximum and minimum temperature had wider differences just as in case of dry period. Though the mean value of PET, 136.48 mm , determined the magnitude of NPP to be negative, rainfall amount exceeded half of the PET will change the magnitude of NPP to be positive. For instance, when PET was 128.34 mm and rainfall was 110.44 mm which was higher than the half of PET, this situation would result in increasing NPP. This gives a good illustration of the combined climatic factors involved in the discriminant function having interrelated effect in governing the NPP production.

CHAPTER 4

CONCLUSION

The investigation of biomass and net primary production of a wet savanna grassland community in a one year cycle revealed a number of facts and hidden features. Comparison made in unburnt and burnt plots showed various features of biomass production in twelve consecutive months. Above-ground live biomass of unburnt plots was found to fluctuate moderately throughout the year, while in burnt plots, the regrowth of grasses produced live shoot biomass at an ever increasing rate up to at least 11 months after burning off the grass. Above-ground dead matter of unburnt plots accumulated in quantity at most during the dry season, whereas in burnt plots, a gradual and continuous increase in dead matter was observed in all months. Shoot-root ratios were found to be lower in unburnt than burnt plots. These differences between the unburnt and burnt swards in their performance of producing biomass and dead matter are clear indication of the influence of fire at the proper moment in the season, because then the external environmental factors are favourable for regrowth and new production. This rather tolerant (for fire) wet savanna grassland seems to process a mechanism in maintaining its community structure through its perennial habit by mobilizing assimilates up and down depending on environmental conditions. Species composition remained unchanged and biomass production of burnt plots went up to almost the same level as of the unburnt ones.

Calculation of the biomass production in terms of net primary production (NPP) showed quite clear the characteristics of this wet savanna grassland. Annual NPP gave practically the same figure, regardless of fire occurance(14.53 and 14.93 ton per hactare for unburnt and burnt plots, respectively). The various components i.e. live and dead shoot and root biomass and amount of decomposed matter showed, however, a distinct difference between the unburnt and burnt swards. Comparing, for instance, the contributions of shoots and roots in the NPP, the so-called shoot-root ratio was 85% for unburnt and 68% for burnt plots. That reflected the balance of growth and development in the shoot and root organs after the savanna was set afire. In fact, above-ground live biomass of unburnt swards turned into dead matter and subsequently decomposed at higher rates than that of the burnt ones. It is important to consider this phenomenon because accumulation of organic matter in soil as carbon sink and source for other soil organisms will be altered when normal swards are burnt. The present study cannot yet quantify this effect, but it is expected that loss of carbon and nutrient leaching from the grassland community will occur in burnt plots. This will consequently reduce soil fertility, and thus will affect growth and development of the sward as well as soil microorganisms. Repetitive burning over periods of a few years of this type of grassland has been shown to reduce NPP which might be due to exactly this reason. The annual NPP, on the other hand, can be altered significantly by some arbitrary change in the external environmental conditions, which this study aimed to analyse.

By using the method of discriminant analysis, it was possible to determine the factors influencing positive NPP (increasing biomass) and negative NPP (decreasing biomass). The environmental variables found to be significant in governing rise and fall of biomass (positive or negative NPP) are potential evapotranspiration (PET), duration of sunshine, minimum air temperature and precipitation rainfall. NPP will have a high probability of being positive when those environmental factors have the conditions of less PET, longer duration of sunshine, lower minimum air temperature and higher rainfall. The limits at which NPP will fall into the negative group(less biomass after a month) are : PET higher than 136.5 mm and minimum air temperature over 22.0 °C. This means that these two factors will induce stress conditions resulting in decreasing biomass, and negative NPP. But sunshine duration over 6.7 hours per day and rainfall over 110.4 mm will modify the trend and change the sign of NPP to positive. It is important to consider the interplay of these four environmental variables on NPP in an integrated way. For instance, when in the dry season

(January, February, March and August) PET is higher than 136.5 mm (and NPP is expected to be negative), a long sunshine duration and available rainfall not less than half of PET will made NPP positive. This was often the case in this study. In the opposite case, to mention another example, when rainfall exceeds PET and the NPP is expected to be negative, the low minimum temperatures during this wet period, as is often the case, neutralize the rainfall effect, and NPP happened to be positive.

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APPENDIX

Appendix 1. The Description of Soil from the Study Site.

Soil Description

Soil name : Visai series, Field symbol : Vi

Classification : a) National : Low-Humic Gley soils
b) USDA : Oxic Plinthaqualts

Described by : S. Anusorn

Date : 7/3/1990

1 Information of site

Location : Ban Klong Hoi Kong , Moo 11, Amphoe Hat Yai, Changwat Songkhla.

Relief and slope : Level; 2 % slope

Physiography : Low terrace

Natural Vegetation or Land Use : Savanna grassland with 4 major species :
Eulalia trispicata,
Lophopogon intermedius,
Fimbristylis tritachya,
Dillenia hookeri

Climate : Climate type : Tropical monsoom climate (Koppen"Am")

Annual rainfall : 2600 mm.

Mean temperature : 27.6 °C

2 General Information on the soil

a. Parent material : Old alluvium

b. Drainage : Somewhat poorly drained

c. Permeability : -

d. Run off : Slow

e. Ground water depth : Below 1 m in dry season

f. Other : Flooded by impounded rain water in rainy season

3 Profile Description

Horizon	Depth	Description
	0-20 cm	Very dark grayish brown [10 YR 3/2] loam; moderate fine to medium subangular blocky structure ; slightly hard dry, firm moist; slightly plastic wet; many vary fine and fine roots; strongly acid [pH 5.5] clear wavy boundary
	20-38 cm	Brown [7.5 YR 5/2] ; clay loam; massive structure; extreamly firm moist; sticky, plastic wet; common fine foot ; strongly acid[pH 5.0]; clear wavy boundery.
	38-60 cm	Pinkish gray [7.5 YR 6/2] with many medium distinct strong brown [7.5YR 5/8] and common fine prominent red[2.5YR 4/6] mottles; clay massive structure ; very firm moist ; very sticky, plastic wet; common fine roots; strong acid [pH 5.0]; clear wavy boundery.

60-90 cm	Light gray [10 YR 7/2] with commom medium prominent red[2.5YR 5/8] mottles; clay ; massive structure ; firm moist, very sticky, plastic wet, common fine roots; strong acid[pH 4.5]: clear wavy boundary.
90-120 cm	Dark brown [7.5 YR 4/4] with common coarse distinct strong brown[7.5YR 5/8] mottle; loamy coarse sand ; massive structure ; extreamly firm moist, slightly sticky non plastic wet; few fine roots; strong acid [pH 4.5]

Appendix 2. Details of the soil analysis at different depths of soil profile of the experimental plot.

Depth	Organic matter	K	Available P	pH	Ec	Texture			
(cm)	(%)	Cold H_2SO_4 (meg/100 g soil)	(mg/kg soil)	Soil : H_2O 1 : 5	micro siemen	% Clay	% Silt	% Sand	
1-20	2.04	0.06	2.48	4.36	42.2	21.70	48.33	29.97	Loam
20-38	0.66	0.04	1.29	4.67	13.1	29.27	39.40	31.33	Clay loam
38-60	0.43	0.06	0.38	4.88	7.7	46.53	35.18	18.29	Clay
61-89	0.09	0.05	0.29	4.63	10.1	26.51	23.59	44.90	Sandy Clay
90-120	0.04	0.03	0.47	4.96	5.8	17.43	19.68	62.89	Sandy loam

Appendix 3. The monthly means and standard error of the above ground dead and total dry matter in unburnt plot.

Month		Live	Dead	Total	(g.m^{-2})
1.April	Mean	161.45	398.53	559.98	
	SE.	15.64	27.28	38.91	
2.May	Mean	179.83	417.82	597.65	
	SE.	13.79	24.79	29.66	
3.June	Mean	267.97	486.27	754.24	
	SE.	12.96	26.25	30.45	
4.Junly	Mean	285.46	465.57	751.03	
	SE.	13.97	17.48	27.13	
5.August	Mean	230.08	495.62	725.70	
	SE.	9.85	15.66	21.95	
6.September	Mean	271.40	634.46	905.86	
	SE.	12.89	25.24	32.94	
7.October	Mean	224.64	535.72	760.36	
	SE.	10.01	16.70	22.40	
8.November	Mean	202.52	576.70	779.22	
	SE.	10.75	22.06	28.16	
9.December	Mean	252.47	597.01	849.48	
	SE.	14.67	23.30	32.46	
10.January	Mean	249.81	648.84	898.65	
	SE.	10.29	15.78	18.26	
11.February	Mean	278.86	700.85	979.71	
	SE.	12.12	28.95	36.36	
12.March	Mean	225.31	543.58	768.89	
	SE.	9.79	21.54	26.15	
	Average	235.82	541.75	777.56	

Appendix 4. The above ground biomass of the four species catagories of unburnt plot.

Month		Catagory 1 (g.m^{-2})	Catagory 2 (g.m^{-2})	Catagory 3 (g.m^{-2})	Catagory 4 (g.m^{-2})
1.April	Mean	112.98	25.38	2.72	20.37
	SE.	12.27	6.13	2.66	2.11
2.May	Mean	124.98	23.94	6.95	23.96
	SE.	12.56	3.78	3.87	3.31
3.June	Mean	148.24	49.21	10.11	60.42
	SE.	9.92	5.45	6.29	4.01
4.Junly	Mean	136.30	45.19	23.35	80.62
	SE.	9.07	6.08	10.54	9.08
5.August	Mean	104.60	38.86	10.06	76.56
	SE.	8.94	4.48	4.70	9.88
6.September	Mean	176.63	24.76	19.06	50.96
	SE.	12.52	3.22	10.75	5.36
7.October	Mean	149.84	23.17	0.30	51.34
	SE.	11.80	2.97	0.29	6.72
8.November	Mean	142.47	24.95	0.38	34.76
	SE.	10.63	3.49	0.26	5.37
9.December	Mean	159.39	40.88	2.72	49.48
	SE.	9.81	5.62	1.63	7.38
10.January	Mean	186.47	22.68	0.76	39.89
	SE.	11.28	5.01	0.50	5.91
11.February	Mean	194.82	28.16	4.03	51.86
	SE.	13.26	4.10	3.88	7.79
12.March	Mean	182.95	9.97	0.26	32.13
	SE.	10.61	1.94	0.25	5.01
	Average	151.64	29.76	6.73	47.70
	Percent	64.30	12.62	2.85	20.26

Appendix 5. The below ground biomass in unburnt plot.

Month		live	Dead	Total $(g.m^{-2})$
1.April	Mean	803.95	314.71	1118.67
	SE.	15.87	31.19	70.86
2.May	Mean	636.90	258.32	895.23
	SE.	29.18	18.17	30.01
3.June	Mean	702.39	252.62	955.01
	SE.	56.00	16.91	55.53
4.Junly	Mean	801.61	202.33	1003.94
	SE.	89.43	23.30	93.99
5.August	Mean	638.09	201.23	839.33
	SE.	51.86	20.40	57.55
6.September	Mean	458.88	168.24	627.12
	SE.	36.53	37.91	37.43
7.October	Mean	693.00	145.29	838.30
	SE.	29.86	19.13	40.03
8.November	Mean	541.95	188.50	730.45
	SE.	30.82	16.92	36.44
9.December	Mean	1015.55	307.68	1323.24
	SE.	87.49	36.41	120.15
10.January	Mean	984.08	234.81	1218.89
	SE.	83.86	20.11	82.43
11.February	Mean	823.10	377.17	1200.27
	SE.	90.81	45.49	88.10
12.March	Mean	770.35	196.55	966.90
	SE.	39.23	14.09	42.51
	Average	739.15	237.29	976.45

Appendix 6. The monthly means and standard error of the above ground dead and total dry matter in burnt plot.

Month		Live	Dead	Total $(g.m^{-2})$
1.April	Mean	16.73	13.47	30.20
	SE.	3.55	3.12	5.72
2.May	Mean	63.74	36.48	99.92
	SE.	5.46	16.09	12.07
3.June	Mean	124.97	36.74	161.71
	SE.	15.14	3.99	17.21
4.Junly	Mean	174.22	85.52	259.74
	SE.	14.53	10.17	22.89
5.August	Mean	196.13	152.15	348.28
	SE.	20.15	11.62	28.78
6.September	Mean	228.66	143.54	372.19
	SE.	15.74	6.87	21.17
7.October	Mean	303.11	201.14	504.25
	SE.	20.74	14.19	32.89
8.November	Mean	303.12	254.57	557.70
	SE.	17.21	10.21	24.47
9.December	Mean	335.30	286.03	621.33
	SE.	31.79	26.26	51.42
10.January	Mean	305.10	291.87	596.96
	SE.	21.52	19.00	38.07
11.February	Mean	328.87	265.72	594.59
	SE.	22.50	24.20	42.97
12.March	Mean	263.86	391.93	655.79
	SE.	6.86	25.18	26.71
Average		220.32	179.91	400.22

Appendix 7. The above ground biomass of the four species catagories of burnt plot.

Month		Catagory1 (g.m^{-2})	Catagory2 (g.m^{-2})	Catagory3 (g.m^{-2})	Catagory4 (g.m^{-2})
1.April	Mean	2.92	11.84	0.00	1.96
	SE.	0.66	2.59	0.00	0.65
2.May	Mean	20.40	31.75	0.00	11.59
	SE.	2.98	4.29	0.00	3.21
3.June	Mean	35.56	37.08	0.39	33.95
	SE.	5.37	6.13	0.28	8.84
4.Junly	Mean	74.57	51.15	1.56	46.96
	SE.	8.38	7.25	1.47	12.86
5.August	Mean	121.64	38.49	0.14	35.85
	SE.	13.52	9.38	0.13	13.37
6.September	Mean	115.25	53.67	0.00	59.74
	SE.	6.69	9.98	0.00	10.23
7.October	Mean	174.11	73.61	3.11	52.28
	SE.	14.24	6.42	2.64	11.92
8.November	Mean	163.89	73.02	1.87	63.35
	SE.	15.84	5.31	1.18	12.00
9.December	Mean	197.29	66.95	0.40	70.67
	SE.	29.48	13.04	0.25	8.09
10.January	Mean	191.72	57.05	9.10	47.23
	SE.	17.60	10.83	8.31	6.99
11.February	Mean	179.41	56.11	0.61	92.73
	SE.	23.30	10.73	0.42	21.92
12.March	Mean	202.91	34.85	7.28	18.82
	SE.	10.06	3.45	4.74	3.41
	Average	124.81	48.80	2.04	44.59
	Percent	56.67	12.16	0.92	20.25

Appendix 8.The below ground biomass in burnt plot.

Month		live	Dead	Total (g.m^{-2})
1.April	Mean	336.23	186.56	522.79
	SE.	25.40	15.16	31.19
2.May	Mean	208.99	143.35	352.35
	SE.	38.46	12.73	43.76
3.June	Mean	184.52	133.68	318.21
	SE.	16.92	20.04	3.34
4.Junly	Mean	121.54	108.23	229.77
	SE.	11.61	6.41	11.33
5.August	Mean	189.68	163.42	353.10
	SE.	28.85	29.93	5.19
6.September	Mean	232.04	49.03	281.07
	SE.	9.89	4.09	14.65
7.October	Mean	151.88	52.83	210.70
	SE.	7.99	7.46	14.55
8.November	Mean	209.70	56.70	266.39
	SE.	8.48	2.72	11.04
9.December	Mean	233.60	80.73	314.33
	SE.	17,35	10.52	6.87
10.January	Mean	300.28	63.54	363.82
	SE.	22.70	4.18	27.81
11.February	Mean	361.92	79.65	441.57
	SE.	36.58	9.40	13.51
12.March	Mean	290.51	85.35	375.87
	SE.	2.24	10.82	12.39
	Average	235.07	100.26	335.83

Appendix.9 Monthly net primary production of the unburnt plot (a) above ground (b) belowground.

(a) Above ground.

Month	Total Live (Y)	Delta Live (Y)	Standing dead	Litter	Total dead	Delta dead (D)	rate (rL)	Loss of litter	rate (rS)	Loss of sd.dead	NPP
1 Apr.	161.45	-15.75	371.91	26.62	398.53	30.10	0.3434	9.1413	0.2173	80.8160	104.31
2 May	179.83	18.38	401.74	16.08	417.82	19.29	0.2614	4.2033	0.3185	127.9542	169.83
3 June	267.98	88.15	465.64	20.63	486.27	68.45	0.0635	1.3100	0.1130	52.6173	210.53
4 July	285.46	17.48	439.65	25.92	465.57	-20.70	0.2002	5.1892	0.1412	62.0786	64.05
5 Aug.	230.07	-55.39	457.54	38.09	495.63	30.06	0.2640	10.0558	0.2720	124.4509	109.18
6 Sept.	271.40	41.33	593.66	40.80	634.46	138.83	0.2196	8.9597	0.2410	143.0721	332.19
7 Oct.	225.76	-45.64	490.79	44.93	535.72	-98.74	0.1003	4.5065	0.0791	38.8215	-101.05
8 Nov.	202.57	-23.19	542.16	34.49	576.65	40.93	0.1134	3.9112	0.0459	24.8851	46.54
9 Dec.	252.98	50.41	570.44	26.21	596.65	20.00	0.1523	3.9918	0.1200	68.4528	142.85
10 Jan.	249.84	-3.14	615.80	33.02	648.82	52.17	0.1650	5.4483	0.1274	78.4529	132.93
11 Feb.	279.00	29.16	662.96	33.37	696.33	47.51	0.1386	4.6251	0.1345	89.1681	170.46
12 Mar.	224.72	-54.28	502.10	42.07	544.17	-152.16	0.2811	11.8259	0.1149	57.6913	-136.92

(b) Below ground.

Month	Live (Y)	Delta Live (Y)	dead (D)	Delta dead	Live dead (biomass)	r	rD	NPP
1 Apr.	803.96	27.57	314.72	-96.08	1118.68	0.1746	54.95	-13.56
2 May	636.91	-167.05	258.33	-56.39	895.24	0.2635	68.07	-155.37
3 June	702.39	65.48	252.62	-5.71	955.01	0.0823	20.79	80.56
4 July	801.61	99.22	202.33	-50.29	1003.94	0.1272	25.74	74.67
5 Aug.	638.10	-163.51	201.24	-1.09	839.34	0.1709	34.39	-130.21
6 Sept.	458.89	-179.21	168.24	-33.00	627.13	0.2260	38.02	-174.19
7 Oct.	693.01	234.12	145.30	-22.94	838.31	0.0765	11.12	222.30
8 Nov.	541.95	-151.06	188.50	43.20	730.45	0.1036	19.53	-88.33
9 Dec.	1015.56	473.61	307.68	119.18	1323.24	0.1308	40.24	633.03
10 Jan.	984.08	-31.48	234.81	-72.87	1218.89	0.1652	38.79	-65.56
11 Feb.	823.11	-160.97	377.17	142.36	1200.28	0.1207	45.52	26.91
12 Mar.	770.35	-52.76	196.56	-180.61	966.91	0.1595	31.35	-202.02

Appendix 10. Monthly net primary production of the burnt plot (a) above ground (b) below ground.

(a) Above ground.

Month	Total Live (W)	Delta Live (W)	Standing dead	Litter	Total dead	Delta dead (D)	rate (rL)	Loss of litter	rate (rS)	Loss of sd.dead	NPP
1 Apr.	16.73	16.73	13.47	0.00	13.47	13.47	0.3434	0.00	0.2173	2.9270	33.13
2 May	63.74	47.01	28.58	7.60	36.18	22.71	0.2614	1.99	0.3185	9.1027	80.81
3 June	124.97	61.23	22.07	14.67	36.74	0.56	0.0635	0.93	0.1130	2.4939	65.22
4 July	174.22	49.25	67.78	17.74	85.52	48.78	0.2573	4.56	0.3798	25.7428	128.34
5 Aug.	196.13	21.91	131.21	20.94	152.15	66.63	0.2794	5.85	0.3346	43.9029	138.29
6 Sept.	228.66	32.53	229.34	24.20	253.54	101.39	0.1277	3.09	0.1361	31.2132	168.22
7 Oct.	303.11	74.45	166.71	34.43	201.14	-52.40	0.2532	8.72	0.2075	34.5923	65.36
8 Nov.	303.12	0.01	217.56	37.01	254.57	53.43	0.0608	2.25	0.0543	11.8135	67.50
9 Dec.	335.30	32.18	258.55	27.48	286.03	31.46	0.1486	4.08	0.1012	26.1653	93.89
10 Jan.	305.10	-30.20	259.29	32.58	291.87	5.84	0.1854	6.04	0.1236	32.0482	13.73
11 Feb.	328.87	23.77	243.35	22.37	265.72	-26.15	0.1650	3.69	0.1732	42.1482	43.46
12 Mar.	263.86	-65.01	365.34	26.60	391.94	126.22	0.1597	4.25	0.1569	57.3218	122.78

(b) Below ground.

Month	Live (W)	Delta Live (W)	dead (D)	Delta dead	Live dead (biomass)	r	rD	NPP
1 Apr.	336.23	220.87	186.56	140.88	522.79	0.1746	32.57	394.32
2 May	208.99	-127.24	143.35	-43.21	352.34	0.2890	41.43	-129.02
3 June	184.52	-24.47	133.96	-9.39	318.48	0.0456	6.11	-27.75
4 July	121.54	-62.98	108.23	-25.73	229.77	0.2937	31.79	-56.92
5 Aug.	189.68	68.14	163.43	55.20	353.11	0.3784	61.84	185.18
6 Sept.	232.05	42.37	49.03	-114.40	281.08	0.2503	12.27	-59.76
7 Oct.	157.88	-74.17	52.83	3.80	210.71	0.2268	11.98	-58.39
8 Nov.	209.70	51.82	56.70	3.87	266.40	0.0680	3.86	59.55
9 Dec.	233.60	23.90	80.73	24.03	314.33	0.1373	11.08	59.01
10 Jan.	300.28	66.68	63.54	-17.19	363.82	0.1629	10.35	59.64
11 Feb.	361.95	61.67	79.65	16.11	441.60	0.1938	15.44	93.22
12 Mar.	290.82	-71.13	84.80	5.15	375.62	0.2278	19.32	-46.66

Appendix 11. Classification results in each cases in 12 months.

Month	Number of cases classified		Total
	Correctly	Incorrectly	
1.April	7	1	8
2.May	4	4	8
3.June	7	1	8
4.July	4	4	8
5.August	7	1	8
6.September	4	4	8
7.October	7	1	8
8.November	5	3	8
9.December	8	0	0
10.January	6	2	8
11.February	6	2	8
12.March	6	2	8
Total	71	25	96
Percentage	73.96	26.04	100.00

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