EFFECTS OF NITROGEN AND PHOSPHORUS RATES ON GROWTH, YIELD AND OIL CUNTENT OF FOUR VARIETIES OF CASTOR (*Ricinus communis* L.)

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A DISSERTATION SUBMITTED TO THE POSTGRADUATE SCHOOL, AHMADU BELLO UNIVERSITY ZARIA, IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF DEGREE OF DOCTOR OF PHILOSOPHY IN AGRONOMY

DEPARTMENT OF AGRONOMY,
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ZARIA – NIGERIA

JUNE, 2012.

DECLARATION

I declare that this dissertation is a record of my own research work conducted in the Department of Agronomy under the supervision of Prof. I. U. Abubakar, Dr. J. A. Y. Shebayan and Prof. B. Tanimu. All information derived from the literature is duly acknowledged in the text and a list of references provided. No part of this dissertation was previously presented for another degree or diploma programme at any university or institution.

A.Y. ABDULLAHI	**……**	**……**
	Signature	**Date**

CERTIFICATION

This dissertation entitled "Effects of Nitrogen and Phosphorus on Growth, Yield and Oil content of four varieties of castor "(*Ricinus communis* L.)" by Asma'u Yakubu Abdullahi meets the regulations governing the award of the degree of Doctor of Philosophy of Ahmadu Bello University Zaria Nigeria, and its approved for its contribution to knowledge and literary presentation.

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DEDICATION

This study is dedicated to my late parents, my husband, children, my sister Fatima Yakubu and my brother Ali Yakubu, for their untiring efforts towards ensuring my success in all endeavours of life.

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In the name of Allah, the beneficient, the merciful. All thanks and praises are due to Allah the most High. I wish to express my profound and sincere gratitude to my Major supervisor, Prof. I.U. Abubakar for his valuable suggestions, objective criticisms and constant support throughout the course of this study. The same sincere appreciation is also extended to Dr. J.A.Y. Shebayan and Prof. B. Tanimu, who co-supervised the work and made significant contributions in the execution of the project and final preparation of this dissertation.

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ABSTRACT

Three trials to study the effects of N and P rates on growth, yield and seed oil content of four castor varieties were conducted during the rainy seasons of 2006 – 2008 on the research farm of the Institute for Agricultural Research, A.B.U Samaru Zaria,(11^0 11' N, 07^0 38E, and 686m above sea level). The treatments, which consisted of three levels of N (0,60 and 120 kg/ha), three levels of P (0, 7.92 and 15.84 kg/ha) and four castor cultivars (Ex-Brazil 1, Ex-Brazil 2, Ex-India 1 and Ex-India 2) were laid out in split plot design with a factorial combination of N and P levels allocated to the main plots, while the four varieties were assigned to the subplots. The treatments were replicated three times. The results revealed that application of 120 kg N/ha and 15.84 kg P/ha produced significantly higher growth, yield, and seed oil content compared with the two lower N and P rates. Ex-Brazil – 1 (a big seeded variety) produced the best yield, growth and yield parameters while Ex-Brazil – 2 (a small seeded variety) produced the highest seed oil content, indicating that the Brazilian varieties were better adapted to Northern Guinea Savanna ecological zone compared with their Indian varieties. Ex-India – 2 was the least adapted variety. The two big seeded varieties (Ex-Brazil – 1 and Ex-India – 2) had the highest height-to-first-capsule and capsule diameter and more S and Na content of leaves. The small seeded varieties (Ex-Brazil – 2 and Ex-India – 1) had the highest number of days to 50% first flowering, higher plant count at harvest and higher Ca, N, P, K and seed oil content. Significant interactions between the treatments were observed with most of the yield and growth characters. Correlation analysis revealed that in 2006, a positive and significant correlation between seed yield/ha and days to 50% first flowering and also with length of raceme/plant, while in 2007 it was positive and significant with number of racemes/plant and also with number of capsules/raceme. Similarly in 2008, there was a positive and significant correlation between seed yield/ha with days to 50% first flowering, LAI at 16 WAS, capsule weight/plant, CGR at 16 WAS, diameter of capsule and length of raceme/plant. In the combined analysis however, a positive and significant correlation existed between seed yield/ha and length of raceme/plant, diameter of capsules, days to 50% first flowering, number of racemes/plant, capsule weight/plant and number of capsules/raceme. Coefficient analysis revealed that the direct and indirect effects of growth characters on yield was more through plant height in 2006 and combined analysis. Coefficient analysis also revealed that the direct and indirect effects and also the percent contribution of some growth and yield components on seed yield were highest through seed oil content. The combination of oil content and number of racemes/plant in 2006, and oil content with raceme length/plant in 2007, 2008 and the combined mean made the highest contribution to yield. From the result obtained in this study, it can be concluded that application of 120 kg N/ha and 15.84 kg P/ha on the Brazilian varieties which resulted in highest growth, yield and seed oil content can be adopted by castor farmers in the Northern Guinea Savanna agro-ecological zone of Nigeria.

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CHAPTER ONE

1.0 INTRODUCTION

Castor bean (*Ricinus communis* L.) belongs to the family *Euphorbiaceae*. It was first named and described by Carl Von Linne (Linneaus) who used the term *Communis* to describe the plant's common occurrence (*communis* meaning "Common") and used the inventive term *Ricinus* to refer to the interesting tick appearance of the seed, which resembles a huge tick engorged with blood (Brigham, 1970 a and b). Castor plant, although commonly referred to as "bean" is not a legume. It is a non-food oil seed crop, whose seed is inedible in the raw state. It is mainly grown for its seeds which contain oil that has many pharmaceutical, medicinal and industrial properties despite its potential toxic effects (Weiss, 1971). According to FAO (1993) the current total average world production of castor seeds stands at 1,582, 300 metric tones per annum, Africa accounts for only about 3.6% of this. In Nigeria, castor mostly grows wild but is produced in small holdings of one to four hectares per farmer with an average yield of 500 – 600kg/ha annually (Denovan and Landsberge, 1999).

There are varied opinions regarding the origin of castor. Sethi (1931) and Zimmerman (1958) held the view that, although castor is cultivated throughout India, it is indigenous to Africa; however, Uzogara *et al.* (1990) affirmed that it is native to India mainly based on the knowledge of the medicinal value of this plant in India. Tropilab (2006) also believed that the plant had been domesticated in many tropical and subtropical regions since ancient times and was found in Egypt as far back as 400 BC. Castor was introduced into the new world shortly after it was discovered about 4000 years ago. Castor crop was one of the ancient oil crops of early Mediterranean

civilization which later spread to India and China. The Egyptians used castor oil as one of the oldest commercial products in lamps more than 4,000 years ago and the seeds have been found in their ancient tombs (Armstrong, 1982). The plant is now naturalized in almost all countries of the world.

The genus *Ricinus* is monotypic (Sethi, 1931). Although grown as annual plants, they behave as perennials in the tropics and sub-tropics. The tall varieties can reach heights of 9.0 – 12.0m, while the dwarf cultivars vary in height from 0.9 to 1.5m depending on soil conditions, including availability of moisture and levels of nutrients (Muensher, 1939). The plant has tap roots and prominent lateral roots below the soil surface.

The castor plant is a tall, glaborous annual, sometime shrubby or arboreous (Colbeth, 1951). The leaves are alternate, broad, palmately seven-to many-lobed and serrated. Flowers are large in terminal sub-panicled racemes, monoecious, apetalous, upper male crowded, lower female disc shaped. The shoots and panicles are glaucous. Leaves are green or reddish of about 30 – 60cm in diameter, membranous, lobed from oblong to linear, acute or acuminate, gland serrated (Vaheeduddin, 1951). Racemes are stout and erect. Male flower measures to about 1½cm in diameter, female calyx nearly as long. Styles often are highly coloured, capsules are 1.5 to 2.5cm long, globosely oblong, smooth or echinate and seeds are oblong, smooth and mottled (Anon., 1955).

The crop is not grown in commercial quantities in Nigeria and efforts were made by a private company, Benagro Nigerian Limited, in Abuja to promote castor production in Nigeria by importing and distributing seeds of different castor varieties freely to interested farmers 2005 with a promise to buying off the produce by these farmers. The

shiny seeds of castor plants have very beautiful and intricate designs. Like the fingerprints of humans, the beautiful designs on castor seeds exhibit infinite genetic variation, and seeds of a variety differ from another variety in design. The seed pod is composed of three sections or carpels which split apart at maturity. Each section contains a single seed, and as the carpel dries and splits open the seed is often ejected with considerable force (Taylor, 1921 and Blarington, 1947).

Bedekar and Gulabuni (1977) described the seeds of most varieties of castor as being encased in a spiny brittle outer shell that is compressed dorsally and grown in clusters on spikes of the plant. The seeds are oval in shape and generally similar to but larger or smaller than a common bean, depending on the variety. The helium which is yellowish white is at the end of the seed. The seeds are mottled dark cream, black, light or dark brown, endosperm copious and white and embryo small while cotyledon is thin and papery (Rao *et al.,* 1981). A large distinct, leafy embryo lies in the middle of a dense oily tissue (endosperm). Muthuvel *et al.* (1987) and Ragavaiah (1988) reported that the seeds are poisonous and the ingestion of only one seed can be fatal to humans.

Narayanan and Gavarayya (1991) observed that castor bean is made up of approximately 75% kernel and 25% husk, and about two thirds of the weight of the kernel is oil. The oil content of various domestic varieties of castor beans from trial plantings are as high as 54% on a moisture free basis. The small seeds can weigh between 0.1 to 1.0g, while the big seeds can weigh from 3.0 to 3.5g.

Anon (1991) analyzed a Brazilian castor bean variety as having a typical oil value of 49%, 18% protein, 13% carbohydrate, 12.5% fibre and 2.5% ash. The beans also

contain the enzyme lipase, which may be readily extractable from the seed. It is insoluble in water and has been shown to catalyze the synthesis of triglycerides as well as the hydrolysis of the oil in the presence of water (Modelle, 2002; Ghosh, 2003).

1.1 Production, Economic Importance and Uses of Castor

In Nigeria, the commercial cultivation of the crop is new and its agronomic requirements have not been reported in details by researchers in the country. However, the crop has been in small-scale cultivation almost all over the country as far back as 1980. In central states of Nigeria, castor plants grow wildly in refuse dumps and abandoned farmlands. Small quantities are presently being grown in Kaduna mostly in backyards (Richael, 2004) and in Zaria in experimental plots.

According to FAOSTAT (2008) the current total average world production of castor seeds stands at 1,582,300 metric tones per annum produced on an approximate area of 1,519.005 hectares with an estimated average yield of 995.5kg/ha. The main castor seed producing countries are India with an annual production of 1,053,000 MT, Brazil (113,145 MT), Mozambique (54,515 MT), Ethiopia (15,000 MT), and Thailand (10,982 MT). Other major castor producing countries include Angola (3500 MT), Kenya (3000 MT), China (2010 MT), Benin Republic (650MT) and Bangladash 335 MT. Europe is the largest importer and user with over 45million kg of castor oil imported annually. Inspite of the increased interest in castor oil, the world production remains relatively low compared with the other oil seed crops (Koutroubas *et al*., 1999). It has also been reported by FAO (1998) that the demand for castor seeds and oil has increased greatly over the years. This has resulted in the annual increase in production in most countries.

Butler (1998) pointed out that castor seeds are not edible in the raw state due to high level of toxic factors such as ricin, haemaglutinins and trypsin inhibitors. The seeds contain enough of the albuminoid toxic, ricin, to cause illness or even death if only one seed is ingested. This, it does by inhibiting protein synthesis in living tissues by specifically and irreversibly inactivating eukaryotic ribosomes. This danger as reported by Anon (2006) from Castor Crop Information and Resource Centre has made most farmers to hold the view that it is better to keep a cobra than to grow castor plants. Similarly, the centre also reported that castor plants are 10 to 1,000 times more potent than potassium cyanide. Besides the toxic ricin of castor seeds, it contains some powerful allergens. People who work with the off-white meal ground from castor may develop allergic reactions such as hives and asthma. In severe cases, they may go into anaphylactic shock which may be fatal (Rhoads and Bloodwork, 1994). This has compelled most farmers to fall out of favour with the crop.

In search of more environmentally friendly fuels, the use of castor oil as “Biodiesel” has proven to have technical and ecological benefits and stands as an opportunity for agricultural development in arid and impoverished areas throughout the tropics and subtropics globally. A castor crop information center (2009) conducted series of investigations on castor bean and concluded that for arid and semi arid regions, growing castor bean in conjunction with jatropha offers the only viable solutions for turning marginal lands into viable economic ones. In the southern states of Nigeria, the dehulled seeds are processed for use as flavour enhancing condiments (Achi, 1994).

The seeds of castor can be fermented and detoxified by the addition of sal meal which contains a high concentration of tannin without destroying the nutritive quality. The seasoning agent formed as a result of this is used as a condiment in soups, salads and stew for rice and yam meals by the Igbo of the Southeast Nigeria and it is called "Ogiri-isi". This condiment has been reported to enhance food flavours thereby making the food palatable and appetizing (Onyeike and Onwuka, 1999). Studies in animal nutrition have shown that castor oil bean meal can be used as protein supplement for ruminants, pigs and poultry (Ani and Okorie, 2005). However, the application of castor oil cake in live stock feed was however limited due to the presence of three potent anti-nutritional factors; ricin, ricinine and thermo stable castor allergens (Dacosta and Lavn, 1961) and possible complicated processing procedures. In addition, castor oil which has long been an article of commerce has a unique physical and chemical properties among all the vegetable oils and has found wide application in modern technology leading to over 400 industrial products (Gobin *et al*., 2001). The oil extracted from castor bean already has a growing international market, assured by more than 700 uses, ranging from medicines and cosmetics to substituting petroleum in the manufacturing of biodiesel, plastics and lubricants. Each hectare of castor oil bean plants planted in arid and semi arid regions produces 350-650/Kg of oil, which in turn produces approximately 350-650/Kg of biodiesel per hectare (Rana *et al*., 2005). These production figures are without any form of high management inputs such as fertilizers or any form of irrigation. This is in large measure due to its versatility. Other reasons why castor production should receive a boost and enhancement as a farming alternative is that the oil when used in medicine, has the ricin that is constantly being referred to by most authors as a

“Magic bullet” isolated from castor seeds and used in targeting and selectively destroying cancerous cells. The compound is capable of a powerful effect on mammalian cells. In pharmaceuticals, the old time purgative and laxative containing castor oil has ricin in low concentrations as an active ingredient. It also has antifungal properties.

Castor oil is also used in industries that produce paints, plastics, nylon, coatings and varnishes. Castor oil is also useful in plastic industries in making insulators. The oil has a drying property in paints. It also serve as an additive in high performance motor oil, as biofuels, in jet engines, as hydraulic fluid, and as greases and lubricants in heavy equipments. It is also used as transformer and aircrafts oil. This is possible because castor oil has a high viscosity at high temperatures. Clothing industry uses castor seeds as raw materials from which sebacic acid, a primary component used in the production of nylon, bristle, plaster, polish, waxes, carbon paper, candle crayon’s and other synthetic fibres is extracted. It is also useful in the formation of artificial leather, printing ink and dyeing of textiles (De Mooy *et al*., 2002).

The oil is used by cosmetic industries to produce creams, shampoo, perfumes and soaps. When the bean is masticated into “Pomace Cake” which can be incorporated into mixed fertilizers, it can alter the genetic code in plants i.e. can act as an allelopath. It also has nematocidal properties that can kill nematode species that have veracious appetite for foliage and crops (Lowell *et al.* 2000). It can also be transformed into concentrated manure for agricultural purposes and as an additive to assist in preparing natural rubber in crumb form known as “hevea-crumb”. In addition,

castor oil and its derivative castor biodiesel are utilized in aircraft and space rockets as it can freeze at extremely low temperatures.

In search for more environmentally friendly and renewable fuel source for the future, the use of castor oil as “Biodiesel” has proven to have technical and ecological benefits, and stands as an opportunity for agricultural development in arid and impoverished areas throughout the tropics and subtropics globally. Horton *et al.* (2006) have conducted a series of investigations on castor bean, and concluded that for arid and semi arid regions, growing castor bean in conjunction with jatropha offers the only viable solution for turning marginal lands into viable economic ones.

In an effort to establish local ongoing demand for castor bean oil, the incorporation of Dove Biotech Bioenergy technologies with raw material feedstock as a means of generating jobs and additional economic benefits will provide a steady income for approximately 4,500 farming families for each 18,000 liter per day of biodiesel production facility installed. Planting castor bean also provides stabilization of marginal lands that are susceptible to erosion by either water or wind.

An unintended but important advantage to a castor bean project as an avenue to reduce global warming is that the plants absorb carbon dioxide, thereby reducing greenhouse gas accumulations in the atmosphere. The estimated carbon dioxide absorption level of castor bean plant is 34.6 tonnes per hectare, with two growing cycles per year (Tropilab, 2006).

1.2 Constraints in Castor Production

Despite its great economic importance, castor growers do not attain optimal production level principally because of the low price associated with castor market. This

has made potential growers to move to the production of other crops. Also, agronomic constraints which include the inadequate supplies of high-quality planting date with improved drought tolerance, shatter and insect resistance, insufficient literature on fertilizer requirement, planting date, spacing, irrigation regime and harvesting techniques are among other factors. The absence or insufficient number of specially built harvesters, lack of proper crushing/processing facilities, unsuitable means of detoxifying and dealleginating castor meal to allow its use in livestock feeds and also inadequate public enlightenment to encourage the crop's acceptance by growers. Other factors include: - the un-economical and inefficient methods of oil extraction, such as by the use of extruders and inadequate mutagenesis and genetic research to eliminate ricin and unfavourable government programs that lack incentives to produce alternative crops in surplus are currently some of the factors militating against mass production of castor.

1.3 Justification of Study

From the foregoing, the importance of castor especially as a source of industrially useful oil cannot be over-emphasized. It therefore becomes imperative to explore all agronomic means to enhance and boost its production since yield and oil content are a function of genetic and environmental influences on crops. In Nigeria, castor production is done at a less than optimal level. An awareness of the various uses of the oil can be used to make a strong case for an increase in castor production as a vital raw material for the chemical industries and the deoiled residue as animal feed resource. There is therefore an urgent need to step up the commercial production of this crop. In Nigeria, castor production is rarely done in commercial quantities. Research on castor agronomy

is limited. There has been so far no substantial encouragement on the part of either the Government or individuals to go into mass production of castor. The technology of increasing the yield of castor plant through improved nutrition according to Oplinger *et al.* (1990) has not been explored from evidence in the available literatures. There is a wide potential to increase the seed yield as well as oil yield of castor recently, in 2004, there was an increased interest in castor production in Nigeria. The Institute for Agricultural Research, Ahmadu Bello University, Samaru, Zaria was mandated by the Federal Government of Nigeria to research on the improvement of castor species production. So far, work has only been done on a few unimproved castor land races collected from the wild since improved seeds were then not available anywhere in the country.

The castor-oil plant is easy to grow and is resistant to drought, which makes it an ideal crop for the extensive semi-arid regions globally. Castor bean could become a farming alternative, providing income for over one hundred million people who could suffer hunger in the poorest regions globally. According to a report of Dovebiotech (2008), production of castor is of great advantage due to the following reasons:-

Recent studies and genetic improvements have increased the oil content of castor bean from 24 to 50%.The plant has also been bred to mature at a shorter height. Whereas the castor-oil plant traditionally reaches three meters in height, making mechanized harvest difficult, there are now varieties that grow to just 1.7meters. These short varieties are mostly commercially grown in Europe. Castor oil has the highest and most stable viscosity index among all vegetable oils, combined with high lubricity, especially under low and high temperature conditions. Castor bean does not compete

with food crops, as it can be grown on marginal lands, which are not competing with food production lands. Castor bean is not competing with food grade oils. Its toxicity is sensed by animals and therefore not foraged on. It is high yielding, yielding as much as 350 – 650kg of oil per hectare when no maintenance is applied to the crop i.e. fertilizers etc, to a high end yield where annual rainfalls happen at the right times, (1000 liter per hectare) The oil seed can be collected by hand, by picking the ripe pods from the plant. It requires only moderate rainfall (approx. 600mm only) and can withstand long periods of drought, but will thrive under higher rainfall as well. It is an uncomplicated crop that requires little attention during its growing periods. Due to its low demand on soil fertility, it is ideal to replant it on marginal lands to prevent desertification and erosion.

This study is therefore aimed at igniting a general interest in castor production in Nigeria since there is a campaign to step up production of the crop as it is well adapted to the climatic conditions of this country. This may eventually translate into economic benefits from possible exportation to other countries as most large castor seeds importing countries depend on outside sources. According to Anon (2002) the world's demand for castor oil is about three million MT per annum valued at about 100 billion starling pounds annually, therefore if castor production is intensified in Nigeria by putting into use the additional information on agronomic practices for maximum yield, Nigeria with time, will be counted among other countries that can fill the gap of castor oil demand worldwide. This will be important in improving Nigerian economy through wealth creation, employment generation and indirectly food security.

1.4 Objectives of Study

It is against the aforementioned background that the study was under taken with the following objectives: -

1. To study the effect of nitrogen and phosphorus on growth, yield and oil content of four castor varieties.
2. To determine the most suitable variety to be cultivated in Samaru.

CHAPTER TWO

2.0 LITERATURE REVIEW

There is a growing interest in castor oil plant owing to the desirable qualities of its oil. In this regard, appreciable work has already been done on the crop in Nigeria. However, a lot still needs to be done to explore all areas regarding its agronomic requirements such as fertilizer and climate, growth habits, morphological characters, dry matter accumulation, mineral nutrient uptake, use and deficiencies. There is therefore, the need to review current efforts related to area of research.

2.1 Nitrogen in Plant Nutrition and Metabolism

As a constituent of many organic solutes and a major component of photosynthetic enzyme, nitrogen (N) plays an important role in field grown plants (Black, 1968). It is the most limiting nutrient for crop production in the savannah ecology of Nigeria (Abubakar *et a.,* 2010).

Despite N being one of the most abundant element on earth, its deficiency is probably the most common nutritional problem affecting plants world wide (Brady, 1974). Healthy plants contain 34% N in their above ground tissues (Souza, 1976). Madhukia and Modhwadia (1993) explained that N is an important component of many important structural, genetic and metabolic component in plant cells. It is a major part of chlorophyll, amino acids and many of the biochemical reactions on which life is based. Nitrogen is also important as component of energy-transfer compounds such as Adenosine Triphosphate (ATP) which allows cells to conserve and use the energy released in metabolism. Also N is important as a constituent of nucleic acids such as Dioxyribonucleic Acid (DNA) which is the genetic material that allows cells (and

eventually whole plants) to grow and reproduce. Without N, there would be no life. It encourages rapid vegetative growth and regulates the utilization of potassium, phosphorus and other nutrients from the soil (Dor, 1994), Brady and Weil (1999) also reported that the growth of most crops is limited more often than not by N deficiency than other nutrients because of the relatively large N requirement by plants. Lowell *et al.* (2000) reported that plants contain more atoms of N than any other element (except carbon, hydrogen and oxygen) derived from the soil. Russel (2000) asserted that the concentration of cations in most plant tissues such as actively functioning leaves are characteristics of the crop and is mostly enhanced by absorbed soil N.

Khadke *et al*. (2000) indicated that plants absorb N from the soil both as ammonium (NH_4^+) and nitrate (NO_3^-) ions, but because nitrification is so pervasive in agricultural soils, most of the nitrogen is taken up as nitrate. Nitrate moves freely towards plants roots as they absorb water. Once inside the plant, NO_3^- is reduced to an NH_4^+ form and is assimilated to produce more complex compounds. Due to the fact that plants require very large quantities of nitrogen, an extensive root system is essential to allowing unrestricted uptake. Plant with roots restricted by compaction may show signs of nitrogen deficiency even when adequate nitrogen is present in the soil (*Khadke et al.,* 2000).

Khadke and Riazuddin (2000) reported that N is important in the manufacture of adequate structural and genetic materials. Lack of it usually results in pale green or yellowish leaves due to inadequate amount of chlorophyll. Older leaves lacking N often become necrotic and die as the plant translocates N from less important older tissues to more important younger ones. Nagabhushanan and Raghavaiah (2005) are of the view

that some plants may grow so rapidly when supplied with excessive N that they develop protoplasm faster than they can build sufficient supporting material in cell walls. Such plants are often weak and may be prone to mechanical injury. Development of weak straw and lodging of small grained crops are examples of such an effect. Deficiency of N in crops leads to stunted growth and restricted root system. Excessive N delays maturation and encourages excessive vegetative growth and photosynthetic areas at the expense of yield and also reduces resistance to drought (Weiss, 1983). Similarly, Hedge (2000) asserted that plants that experience N deficiency usually develop small leaves with thick-walled cells that are hard and fibrous. They further reported that leaves of plants appear dark green in colour when N is in excess and become yellow and chlorotic when N is inadequate.

2.2 Effects of N on Growth and Yield of Castor

The significant effect of N on growth and yield characters of castor is probably as a result of the positive effects of N at enhancing crop growth (Kulkarni, 1959 and Kostrinsky, 1968). A similar view was reported by Anon (1971) who found that an increase in N supply to castor promotes leaf expansion due to production of extra protein. This in turn increases the leaf area available for photosynthesis but at the expense of yield and reduces resistance to drought. However, Salatenko (1977) was of the view that the higher the doses of N up to 120 kg N/ha applied to any variety of castor, the better the performance in terms of growth and yield. The significant effect of N levels on seed yield of castor is probably due to the fact that the element promotes growth and consequently the assimilate produced are channeled to the seed (Rachie and Silvestre, 1977). Nitrogen fertilizer rates are determined by the crop to be grown,

yield goal, and quantity of N that might be provided by the soil (Mokwunye, 1979). Nitrogen rates needed to achieve different yields with different crops vary by region, and such decisions are usually based on local recommendations and experience. Armstong (1982) and Weiss (1983) reported that initial application of 40 – 120 kg N/ha increases the yield of castor by 100%. Whingwiri *et al.* (1987) reported that growth and yield characters were increased by 60% when minimum of 80 kg N/ha was used than other lower N doses. This, they added is attributed to the high demand for N by castor. In addition, seed yield increases up to 70% have been reported in castor with the application of N rates up to 90 kg N/ha (Mathuvel *et al., 1987;* Savan and Giri, 1987; Rao and Ventatesuwarlu, 1994). Castor plants subjected to doses of N higher than 120 kg N/ha tend to increase stem growth at the expense of assimilate partitioning to reproductive tissues. This conforms to the work of Vijaya *et al.* (1997) who reported that castor flowers earlier when provided with 120 kg N/ha indicating that they attain certain level of development earlier at this rate. Flowering, as explained by Jana *et al.* (1990) is an important physiological process in the development of castor and has a profound effect on the final yield that can be obtained. However, Mahalle *et al.* (1991) and Jenkins (1993) did not observe any response by castor as N application is increased upto 80 kg N/ha. This disparity can probably be attributed to differences in the soils and or varieties of the crop used (Teklewold and Alemeyehu, 1993). Similarly, Abubakar *et al,* (2010) reported that castor flowers earlier when subjected to 120 kg N/ha indicating that they attain certain level of development earlier at this rate

In India, application of 45 kg N/ha using sulphate of ammonia as source of N did not increase castor seed yield (Gandi *et al.,* 1994), whereas Anon (1997 and Vijay *et al.*

(1997) found that high N treatment (120 kg N/ha) gave higher total dry weight and seed yield in castor than low N (40 kg N/ha) treatment. Hedge (2000) recommended 60 kg N/ha as the minimum and 120 kg N/ha as the maximum N quantity for maximum yield in castor. Similarly, in Andhra Pradesh farm in India, it was reported by Khadke *et al.* (2000) that castor responds to N at levels higher than 30 kg N/ha given in the form of farmyard manure. The residual effects continued for another two years though in decreasing intensity. In the United States however, Khadke and Riazuddin (2000) reported that a general application of 45–135 kg/ha of nitrogen increases yield by 100% when split-applied.

In a 3-year N.P.K field trial conducted by Gobin *et al. (*2001) and Modell (2002) using "Wale" variety of castor, it was observed that the application of 20 kg N/ha increased mean yield by approximately 50% (i.e. from 1690 to 2530 kg/ha), while yield of 10 kg N/ha was increased by 12% only. He explained that insufficient N might culminate in stunted plant, firing of older leaves and premature senescence thereby reducing yield. Excessive N levels, they added, tend to promote excessive growth of Castor while reducing resistance to drought. On the other hand, Hikwa and Mugwira (1997) reported that castor in Zimbabwe tolerated low level of N with highest yield achieved at 60 kg Nha.

2.3 The Role of Phosphorus (P) in Crop Physiology

According to Brigham and Spears (1961) and Attia *et al*. (1979) P is an essential element classified as a macronutrient because of the relatively large amounts of P required by plants. One of the main roles of P in living organisms is in the transfer of

energy from one reaction to drive another reaction within cells. Adequate P availability for plants stimulates early plant development and hastens maturity (Smith *et al.,*1981).

Phosphorus is absorbed by plants in the form of H_2PO_4 and HPO_4 whose availability is highly influenced by soil pH, soil moisture and the cations in the soil solution. De Mooy *et al.* (2002) asserted that P is an important plant nutrient for its role in the formation of high energy molecules and synthesis of cell constituents. It also plays important roles in the formation and translocation of carbohydrates, fatty acids, nucleoprotein and the availability of other nutrients such as N. It stimulates seed and root development and improves quality of seeds and fruits. In view of these critical functions, finding an optimum rate and efficient use of P fertilizer has become central to improving crop yields in the savanna, where available-P is reported to be extremely low (Lowell *et al.,* 2002). However, Mours *et al.* (2002) reported that a water-logged soil condition can deprive castor of the available P no matter the quantity applied.

2.4 Effects of Phosphorus on Growth and Yield of Castor

Kulkarni (1968) and Brigham (1970) reported the advantage of matching different castor varieties with required doses of P for good growth, high yield, elimination of capsule shattering and uniform hull-strength and thickness are necessary for castor. The effect of P ions in castor plant as explained by Anon (1971) is such that it combines with other elements in the soil such as Calcium, Magnesium, Aluminum and Iron to form solid compounds. The absorbed P and the newly formed solids are relatively available to meet castor growth needs. He added that continued application of excess P than

required by castor only increases the fertility of the soil, but much of the added P becomes fixed and unavailable therefore rendering it to be a waste.

Weiss (1971) and Moshkin (1986) affirmed that P is one of the most limiting nutrient in castor production. Application of P has always been accompanied by a significant increase in good growth and increased seed yield. Its application in the form of single super phosphate is beneficial because of its sulphur content that is good in oil production of castor. Salatenko (1976) however, reported that application of 10 – 15 kg P/ha significantly increased vegetative growth and early seed formation that led to early maturity of the crop. Other investigators have reported 100% increase in yield responses only when P rates were raised to up to 15 kg P/ha (Uzogara *et al.* 1990; Corbette, 1993; Dastur, 1993; Gandhi *et al.,* 1994 and Rhoads and Bloodworth, 1994). Anon (1994) on the other hand opined that there is a general increase in growth and yield of castor as a result of applied P. Reports of Rao *et al.* (1995) showed that applying P up to 15 kg P/ha increases growth and yield of castor by 70 – 90%. A similar result was reported by Onyeika and Onwuka (1999) and Lowell *et al.* (2002) using 10 – 15 kg P/ha and 15 – 20 kg P/ha respectively.

2.5 Effect of Interaction between N and P on the Growth, Yield and Growth and Yield Components of Castor

Hardin (1974) and Dorenbos and Kassam (1979) explained the complementary effect of N and P on castor in which N tends to promote vigorous growth and increases the photosynthetic capacity of the crop in terms of increased leaf area index (LAI) while P encourages seed and root development thereby increasing yield as a result of increased solubility and uptake of P in the presence of N. It was also reported by Weiss

(1982 and 1983) that the application of N along with P in castor produced the highest absorbed shoot K concentration than when neither N or P was applied. This, as explained by Goebel (1980) and Subba Reddy (1999), may be attributed to the vigorous vegetative growth and root development resulting in increased uptake of K.

Another supportive report on N and P interaction on the growth, yield, growth and yield components of castor as reported by Salih (1981) and Armstrong (1982) explained that the complementary role played between N and P on vegetative and reproductive growth of castor could be attributed to the ability of N and P fertilizer combined to promote foliage growth, increased meristematic and physiological activities of castor thereby resulting in the synthesis of more photo-assimilates which are used in producing higher yield. Alber and Alber (1993) opined that castor exhausts the soil quickly, therefore, adequate fertilization of N and P are necessary. They further reported that although potassium (K) is also needed for proper growth and development of castor, it is only required in relatively small quantities of approximately 0.23 – 0.45 Cmol/kg. In most cases, the quantity of K present in most soil types is adequate for castor growth and that additional application may not be necessary (Domingo and Crooks, 1999).

Daiz *et al.* (1992) and Marinkovic *et al.* (1994) recommended that for 100% effective growth and yield in castor, P should be applied alongside N. In addition, Domingo and Crooks (1999) conducted extensive trials on farmers fields with inorganic fertilizers and found that under rain-fed conditions the most economic composite dose was 60 kg N/ha + 15 kg P/ha + 10 K_2Okg/ha. They found that the growth and yield of castor is maximally achieved with increase in quantity of N and P above the rates when

the three elements are combined, but not when applied separately. They were also of the view that even the new dwarf varieties of castor are more fertilizer responsive and require about to 120 kg N/ha + 20 kg P/ha + 10 K_2O/ha under rain-fed conditions to obtain good yields. They reaffirmed that it is only possible when these fertilizer types are applied together and that high levels of N were not recommended without application of P as they perform complementary functions. Anon (1991) from the Indian Central Oil Seeds Committee is of the view that the adequate doses of N and P are necessary for early vegetative growth, flowering and better yield than when initial growth is limited. In the U.S.A, however, Mours *et al.* (2002) indicated that fertilizer trials in Kansas, Kentucky, Missippi, Missouri and Oklahoma, failed to show any marked increase in yield in ten different castor varieties from N, P or K either alone or in combination. The only significant increase from any treatment was with K alone at Princeton in Kentucky. In the same trial, P with N or K failed to produce any significant increase. However, in view of the fact that castor plant grows very rapidly, it is considered to require a soil in which the nutrients are readily available for encouraging results, provided moisture stress and temperature are not prevailing at the time of growth of castor (Richael, 2004). However, according to Horton *et al*. (2006) irrespective of N and P levels used in cultivation of castor, water stress is an important factor to which the crop should not be subjected. This is because it can lead to large transpirational demand which consequently can lead to increased water deficit and moisture stress even in high N and P supplied crops. Tropilab (2006) reported that when 40 – 120 kg N/ha and 10 – 16 kg P/ha are applied to castor while in a period of water stress, these doses of N and P tend to assist in greater evaportranspiration during early stages of stress period, more

effective soil water extraction by the root system, low leaf diffusion resistance in response to the stress and less stomatal closure. These may result in slow response to water shortage and consequently poor growth by plants well supplied with N and P.

In a field trial conducted by Mohammed (1967) on castor CV. Aruna, the results indicated that after using three different fertilizer combination rates i.e. 120 kg N/ha + 16 kg P/ha, 100 kg N/ha + 10 kg P/ha and 80 kg N/ha + 10 kg P/ha as his treatments for three years, there was a progressive increase in number of leaves, number of branches, crop growth rate, LAI, plant height and plant dry weight with each increase in N and P levels each year. Another interesting observation made by Singh and Singh (1977) was that the percent contribution of these growth parameters to the total yield was maximum 59% under the first treatment and decreases with progressive decrease in fertilization rate of N and P (46.1 and 42.2% under the second and third fertilization combinations, respectively). Similarly, Brigham (1993) and Chibber (1994) noted a highly significant positive correlation between seed yield of castor and vegetative dry matter and some yield components in castor. However, despite adequate fertilization, moisture stress during critical stages of growth are likely to hinder castor development (Hanada, 1977 and Mokwunye, 1979). Similarly, Doorenbos and Kassam (1979) reported that amongst the various critical stages of growth of castor as far as environmental limitations to yield, especially as moisture is concerned, is the period between 30 and 60 days after sowing. Adverse weather conditions during this stage limit the yield while favourable conditions increase the yield. On the other hand, Czapla and Johnston (1990) and Jana *et al.* (1990) are of the view that apart from adequate fertilization of N and P, maximum and minimum temperatures are also critical to the growth and yield of castor. They

suggested 30 and 20^{0}C as the maximum and minimum temperatures respectively being necessary for favourable seed setting to maturity in order to achieve high yield in castor.

In a similar study made by Czapla and Johnson (1990) in two years on castor 'Hale' and 'Aruna' varieties, where each was exposed to two different fertilizer rates of 160 kg N/ha + 20 kg P/ha and 140 kg N/ha + 18 kg P/ha, the total bean yield of castor, comprising of number of racemes, number of capsules, 100-seed weight and seed yield per hectare, along with data on percentage contribution of each of these post-harvest parameters to total yield, revealed that the different varieties and fertilization rates had significant effects on the total yield of the two castor varieties. They opined that the higher the quantity of N and P on the two varieties, the higher the yield and concluded that yield of the two castor varieties averaged over the two years showed significant inter-annual variability and interactive effects due to different N and P quantities. As inferred by Rao *et al.* (1995) and Salatenko (1977), neither N nor P acts in isolation but combinedly influence castor crop yield. The multiple regression equation developed in their work with seed yield as dependent variable and different N and P rates as independent variable, revealed that 61% of variation in seed yield was explained by the different quantities of N and P. This result is similar to that reported by Cooper and Johnson (1994) and Vijaya *et al*. (1997), where varying N and P rates caused variation in capsule weight per plant, diameter of capsules, number of seeds per capsule, raceme length per plant and the general growth and development of different castor varieties. According to FAO (1998) a model predicting total yield can be utilized to identify optimum fertilization rates needed for proper castor growth based on the available varieties. It can also be used in formulating suitable growth models to stimulate yields

of castor and also in delineating areas with optimum agro-climatic environments for achieving potential productivity of castor. This is necessary because among various stages of crop growth, reproductive period translates into better and productive post-harvest parameters as reported by Grimmer *et al.* (1999) and Kaurobas *et al. (*1999) were observed to be the most critical as far as N and P rates are concerned not only in castor but in many other oil crops like groundnut, soyabean, etc. Sufficient quantities of N and P during this stage limit the yield while adequate quantities increase the yields.

Similarly, Denovan and Landsberg (1999) confirmed that the yield responses of castor bean to varying quantities of N and P brought out that castor crop requires quantities of N and P not exceeding 120 kg N/ha and 15 kg P/ha. Lower doses than these ultimately resulted in significantly lesser yields. Their studies also revealed that with management practices like fertilizer dose, weeding and plant protection adequately maintained, higher seeds, racemes and capsules sizes and weights can be achieved. Higher yields, they added, were promoted through adequate growth of these parameters that contributed maximally to yield of any castor variety. This was due to the dominant physiological characteristics, adequate N and P, soil conditions and congenial environmental conditions prevailing during the reproductive period, like higher moisture availability, longer photo-period and optimum thermal regime.

2.6 Effect of Split Application of N in the Growth of Castor

Denovan and Landsberg (1963) and Lazorov (1965) are of the view that timing of N application has a major effect on the efficiency of N management systems. Nitrogen should be applied to avoid periods of significant losses and to provide adequate N when

crop needs it most. Split application of N to castor prevents further losses, particularly those due to denitrification or leaching.

Research work on the split application of N in castor in Zimbabwe conducted for two seasons by Denovan and Landberg (1963) showed overall seed yield increases of between 23 and 45% when N was applied whole. However, increase in yield rose to between 50 and 80% when N was applied in split halves. Elsewhere, seed yield increases have been reported with split N applications (Salatenko *et al*., 1976 and Sundarensan *et al.*,1977) In Zimbabwe, Hikwa and Mugwira (1997) reported that two split applications of 60 kg N/ha resulted in higher seed yield of castor than sole dose of 90 kg N/ha. The first dose incorporated with P at planting, was to enhance growth of the seedlings providing all the benefits of N to crops; while the second application at floral initiation enhanced seed setting (Nnadi *et al.,* 1981 and Lawn, 1982). Similarly, Bangerth (1989), Anon (1994) and Hikwa and Mugwira (1997) reported that split application of N to castor helped to minimize loss of N by leaching and volatilization. They explained that, splitting N has a seed yield advantage over single application in a good rainfall season under medium to high initial N in the soil. The increased efficiency of such N split application was shown by the highest yields which were achieved at 120 kg N/ha instead of 180 kg N/ha in single N application as reported by Hikwa and Mugwira (1997). This saves cost of using excess N more than necessary. Split N application helps to increase average yield above that achieved in single N application in different seasons (Brady and Weil, 1999). However, Moursi *et al.* (2000) explained further that split N applications are only beneficial to castor when seasonal rainfall is greater than 700 mm as the yield of castor increases with increasing moisture content of

the soil. At the 30 and 60 kg N/ha rates, there were no differences between the sole and split N application. However, at 90 and 120 kg N/ha, when N was split, a delay in crop maturity was upto 12 days. They concluded that a difference in the yield performance was attributed mainly to seasonal precipitation. They however, agreed that split application can have a positive effect on the vegetative growth of castor.

The responses to split N application appear to be primarily due to the status of available N in soils and the rainfall regime (Moursi *et al.,* 2000). These responses generally coincided with medium status of available N in soils suggesting the thresh-holds for yield benefits from split N application. Riazuddin (2000) also observed the effect of split N application on the increased number of racemes/plant produced in "Hale" castor variety. The average numbers of racemes/plant and duration to maturity of the primary racemes were measured in consideration that they could be used as good indicators for seed yield.

Similarly, in field experiments, Mours *et al.* (2002) have shown that there were yield reductions of 41% and 58% in "Hale" in split N application as rainfall decreased by 53 and 32%, respectively. They concluded that the yield advantage of split over sole application was dependent on the amount of rainfall, particularly in a good season. Also Rachael (2004) observed that there was an indication that castor can tolerate "low" levels of available N.

2.7 Varietal Responses of Castor to Fertilizer Application

According to Pathak and Verma (1965) and also Singh (1968), castor growth and seed yield are usually determined by several inter-related components notably amongst

these are the genetic make up of the variety, the effect of the environment and to a large extent the level of field management.

There is a wide range of varieties of castor crop. The varieties differ in their response to fertilizer rates, branching habit, seed types, colour of the stem and branches (red or green), the nature of capsules (smooth or shiny), duration and the size and colour of seeds (Rao and Vantateswarlu, 1974 and Knight 1979). In addition, castor crop types, according to Saletenko (1975) differ genetically in their potential productivity and their relative response to management practices especially fertilizer use practice, water management and field situation. In a similar report, Prodon *et al.* (1985) and Singh and Sharma (1985) reported that castor varieties differ in their ability to partition dry matter into capsules and seeds in response to environmental factors and fertilizer doses. They further reported that the small seeded castor varieties are usually late maturing and thus more time is allocated to the partitioning of assimilates into racemes, capsules and seeds. Mathuvel *et al.* (1987) also explained that high seed yield in castor is associated with the crop adaptability to its environment be it the big seeded or the small seeded provided there is adequate supply of N and P. However, Savan and Giri (1987) reaffirmed that oil content for small seeded castor varieties is always higher than that of the big seeded, especially when given adequate fertilization.

Baluch (1987) and Lauretti (1990) found that variation in seed type and sizes is more often genetic in nature. They explained further that the big seeded varieties of castor usually exhibit more profused branching with taller plant than the small seeded varieties. They however added that more seed yield is likely to be produced by the big seeded varieties given their level of fertilization and moisture requirements. Muthuvel *et*

al. (1987) are of the view that the more the doses of N applied to any castor variety, the better the growth and yield.

Savan and Giri (1987) reported that there are variations in the genetic composition of the small and big seeded varieties of castor. This leads to various degrees of differences exhibited in their growth and yield characters and also in their fertilizer requirement. Bangerth (1989) is of the view that the short varieties of castor more frequently produce smaller seeds and are more fertilizer and moisture responsive. Oplinger *et al.* (1990) reported that the taller varieties of castor form their flowers early and most often produce big seeds. They explained further that the early formed flowers and seeds are more successful at early and better seed setting as this result to early maturity. Anon (1991) explained that the taller castor varieties when given adequate fertilization of 120 kg N/ha + 15 kg P/ha will produce higher numbers of racemes and of seeds per capsule. This contributed significantly to their seed yield than the small seeded types. Also, from the findings of Roetheli *et al.* (1991) the big seeded genotypes consistently showed higher CGR and LAI values after flowering than the small seeded varieties when the N level is above 100 kg/ha. In addition, from the work of Anon (1991) where a combination of 120 kg N/ha + 15.80 kg P/ha was used in fertilizing different size seeded varieties of castor, it was found that a higher python-mass was associated with longer duration genotypes. He concluded that modern taller cultivars are associated with higher python-mass than with higher partitioning efficiency. Also Dor (1991) reported that the higher LAI, to a great extent, determines biomass accumulation through its effects on radiation interception and photosynthetic activity. It was also reported that castor varieties supplied with low N and P were observed to have limited

leaf area available for photosynthesis, reduced transpiration, conserved stored soil water and consequently reduced plant water requirement (Rao *et al. ,* 1995).

In Brazil, varieties grown vary in maturity from five – ten months depending on the fertilization rate. Some varieties like 1123, and UC 53 matured within seven – ten months when 120 kg N/ha and 15 kg P/ha were applied. Others such as Baker 44 Lynn mature within five – seven months with the same fertilization rate. In India, hybrids like NPH-1 (Aruna) and TMVCH mature between five – six months with the application of 120 kg N/ha and 15 kg P/ha. It was reported that no K_2O application was necessary since castor requires only a little quantity of it which in most cases is being supplied by the soils in which the castor is grown (Black, 1997). It was reported by Gulabani and Bacdeker (1997) that castor varieties differ in their ability to partition dry matter to seeds in response to environmental factors such as temperature and solar radiation intensity as these may have a significant effect on different phonological stages of growth. The advantages of matching these annual varieties with the necessary fertilization rate, are for high yield potential, elimination of capsule shattering and uniform hull strength and thickness. However, the major disadvantage of these varieties is susceptibility to pests and diseases as inferred from the work of Hikwa and Mugwira (1997). In India, the average yield of rain-fed castor varieties range from 200 to 500 kg/ha and 500 – 800 kg/ha when 60 kg N/ha + 15 kg P/ha and 120 kg N/ha + 16 kg P/ha were applied, respectively (Gulabani and Bacdekar, 1997).

Marve and Clarke (1997) worked with two varieties of castor (Hale and Lynn) using the same fertilization rate of 120 kg N/ha and 16 kg P/ha and found that the two

varieties behaved differently in terms of maximum yield. They concluded that each variety has its own different fertilization requirement and growth habits.

Kautroubas *et al.* (1999) reported that varietal differences of castor are not affected by soil fertility. This contradicts the findings of Denovan and Landsberg (1999) who have shown that there is a marked difference in crop growth, crop yield, seed weight, capsule weight, number of capsules and racemes, nutrient content of leaves, oil production and other yield components among the 'Hale', 'Lynn' and 'Corner' varieties of castor when different rates of N and P were applied. Denovan and Landsberg (1999) also reported that the most economic dose of the older castor varieties was 120 kg N/ha + 16 kg P/ha. With higher doses of N, these varieties only grow taller with much vegetative growth but less yield potentials. The new varieties however, require higher doses of up to 110 kg N/ha + 15 kg P/ha.

Exploratory field experiments in Zimbabwe as reported by Hedge (2000) showed that there were hardly any interactions between P and K applied on many castor varieties. Responses to N application were however apparent. This finding is contrary to that of Khadke *et al.* (2000) who found that the yield of 'Conner' castor varieties fail to show any marked increase in yield from N, P or K applications either alone or in combination. Also Lowell *et al.* (2000) found that 'Aruna' cultivar when grown in sand culture with complete Hoagland nutrient solution, or the solution without N and P among others, the effects on morphological characters, dry matter accumulation, relative growth rate, leaf area index and ratio, chlorophyll, proline contents, nitrate reductase activity, oil content mineral uptake and mineral use deficiencies were recorded. In all, deficiency symptoms were obvious in the absence of both N and P.

Domingo (2001) reported that application of 90 kg N/ha and 15 kg P/ha to twelve different land races of castor have been found to increase both yield and growth. This finding is similar to that of Shaw (2002) Rana *et al.* (2005); Tropilab (2006); and Horton *et al.* (2006) who used different N and P rates on different castor varieties and had the similar results.

Anon (2006) affirmed that there was an overall seed yield increase of between 23 and 45% and between 30 and 60% when 60 and 90 kg N/ha were applied, respectively. The same effect was observed with the application of P on different castor varieties. Exploratory field experiments in 1981-87 have shown that there were hardly any interactions between N and P applied to T3 castor varieties. Responses to N application were however apparent (Tropilab, 2006). Horton *et al.* (2006) reported that the highest yield of castor crop variety T3 was obtained by applying 120 kg N/ha + 15 kg P/ha. Anon (2006) observed in a series of experiments performed on “Aruna” of castor that dry matter accumulation during ripening phase is greatly influenced by N and P application at the rate of 120 kg N/ha and 20 kg P/ha respectively.

In a series of experiments on “Conner” Tropilab (2006) asserted that optimum and minimum temperatures of 30 and 22^0C respectively are favourable for seed setting to maturity by providing 120 kg N/ha and 16 kg P/ha, in order to achieve maximum yield. Similarly, Horton *et al.* (2006) explained that “Aruna” grows best where temperatures are rather high throughout the season, but seed may fail to set if it is above 38^0C for an extended period when fertilization rate is below 150 kg N/ha + 20 kg P/ha. It also prefers a pH of between 4.5 and 8.3.

2.8 Effect of N, P and Variety on Yield and Oil Content of Castor

Anon (1992) from the Commonwealth Economic Community, reported that seed oil content of castor is influenced by genetic composition although environmental factors could modify its content and quality. He added that castor responds to N and P levels higher than 30 kg N/ha and 10 kg P/ha, respectively. Higher rates than these were observed to greatly increase the yield and oil content of castor plant seeds. Ananda *et al.* (1993) reported that generally in castor, seed oil content and most important elements are associated with seed size, with large seeded varieties producing less oil than small seeded. Similarly, Brigham (1993) explained that oil contents of small seeded castor varieties were also higher than the big seeded, especially with adequate fertilization. Brigham (1993) reported that there were significant increases in seed yield and oil contents of castor when 120 kg N/ha and 15 kg P/ha were applied. His findings further revealed that the correlation between seed yield and oil yield due to applied N and P was positive and significant. He concluded that the significant relationship between N and P on the oil yield was synergistic, causing improvement in seed and oil yield. However, Vijaya *et al.* (1997) reported that adequate amounts of N and P must be available to produce only high seed yields of castor but not an increase in oil content. If soil is deficient in N, then, 90 to 100 kg N/ha is usually needed for maximum yield but not for oil content increase. If P is needed, application should be made with a minimum quantity of 10 to 15 kg N/ha as it is always a limiting factor in tropical soils.

Lowell *et al.* (2000) reported that high castor seed yield is not associated with more oil content irrespective of fertilizer rates used. This was confirmed through series of trials using the two different seeded varieties, and got an average yield of 3.08 and

2.83 tonnes per hectare with 35.14 and 48.3% oil for the big and small seeded varieties, respectively using the same N and P rates. Similarly, Khadke and Riazuddin (2000) reported in their work with 1123 which is a big seeded variety and UC53 that is small seeded using 120 N + 15 P kg/ha. Average seed yields of 335.9 and 224.6 kg/ha with oil content of 30 and 51.2%, respectively were obtained. However, a similar report of Khadke *et al*. (2000) reaffirmed that modern semi-dwarf, small-seeded castor cultivars are associated with higher partitioning efficiency, resulting in more oil deposition in their seeds, provided N and P quantities exceed 100 N and 15 P kg/ha, respectively.

In another report, Taylor (2001) is of the view that the oil content of castor varies with the quantity of N and P applied. It generally increases from the first to the last harvest as the capsules mature at different times. They observed that the oil content of castor goes on increasing even after the capsule's dry stage is reached i.e. even after the fruits on the spike have dried. The initial increase in oil content continues for over 30 days after the dry stage. At the latter, castor requires maximum nutrition from N, especially from the second application. Thus, the correct time of harvest would not be immediately after the fruits have dried but at least 20 to 30 days after wards.

Shaw (2002) reaffirmed that the rate of increase in oil content of castor varies from year to year, but noted that is not dependent on the amount of N or P, indicating that seasons have considerable effect on the rate of deposition of oil. In the first 30 days after fruit discernibility, he explained, only a very small quantity of oil will have been deposited, in the next 10 to 20 days, a very rapid increase takes place and nearly two-fifths of the oil is deposited, in the next 10 days from the 50^{th} to 60^{th} day after fruit discernibility, the rate is nearly doubled (almost about 80%) of the total oil deposition,

after 60 days, the rate declines rapidly. The period during which maximum oil is deposited thus varies from season to season and on variety, but not on the quantity of N or P.

Ghosh (2003) observed that different strains of castor were tried in different parts of Rajendranagar farm in India with varying soil nutrition and climatic conditions, but everywhere the strains maintained their original oil content. In the same location, similar results were observed. Brigham (2003) asserted that no difference was found in the oil content of castor grown with varying N and P levels when the capsules became dry and those harvested when one or two capsules in a spike showed sign of drying and immediately dried in the sun. This result showed that N and P rates do not influence the quantity of oil produced in castor. It is therefore not necessary to delay harvest till all the capsules in a spike are dry as suggested by Khadke and Riazuddin (2000). The harvest can be taken up when one or two capsules show sign of drying but the produce must be immediately sun-dried thoroughly. Ghosh (2003) also performed series of experiments to investigate the effect of fertilization on oil content of castor. He worked on different rates of N and P. These experiments were conducted at Rajendranagar farm in India. When the oil contents of the seeds under different treatments were determined, there were no significant differences. Hence, it was concluded that the treatments used in those fields have no effect on oil content of castor.

Rana *et al.* (2005) conducted other studies on a large number of castor lines. They found that these lines with varying oil content ranging from 45% to 56% were all constant for oil content when grown under varying quantities of N and P soil and climatic conditions. They ensured in the experiments that just as morphological characters were

observed every year to maintain the purity of strains, the oil content was also determined every year to see if any of the strains was deteriorating in oil content. But, for so long, no oil deterioration was observed in any strain. Similarly, Brigham (1993) noted a highly significant positive correlation between seed yield of castor and vegetative dry matter and some yield components in castor. However, despite adequate fertilization, moisture stress during critical stages of growth were likely to hinder castor development (Hanada, 1977, and Mokwunye, 1979). Similarly, Doorenbos and Kassam (1979) reported that amongst the various critical stages of growth of castor, as far as environmental limitations to yield, especially moisture is concerned, is the period between 30 and 60 days after sowing. Adverse weather conditions during this stage limits the yield while favourable conditions increase the yield. On the other hand, Jana *et al.* (1990) are of the view that apart from adequate fertilization of N and P, maximum and minimum temperatures are also critical to the growth and yield of castor. They suggested 30 and 20^0C as the maximum and minimum temperatures, respectively necessary for favourable seed setting to maturity in order to achieve higher yield in castor.

In a similar study made by Czapla and Johnson (1990) in two years on castor “Hale” and “Aruna” varieities where each was exposed to two different fertilizer rates of 160 kg N/ha + 20 kg P/ha and 140 kg N/ha + 18 kg P/ha, the total seed yield of castor, comprising of number of racemes per plant, number of seeds per capsules, 100-seed weight and seed yield per hectare along with data on percentage contribution of each of these post harvest parameters to total yield revealed that the different varieties and fertilization rates had significant effect on the total yield of the castor varieties. They

opined that the more the quantity of N and P on the two varieties, the higher the yield and concluded that yield of the two castor varieties averaged over the two years showed significant inter-annual variability and interactive effects due to different N and P quantities. As inferred by Rao *et al.* (1995) and Salatenko (1977) neither N nor P act in isolation but combinedly influence castor crop yield. The multiple regression equation developed in their work with seed yield as dependent variable and different N and P rates as independent variable, revealed that 61% of variation in seed yield was explained by the different quantities of N and P. This result is similar to that reported by Vijay *et al.* (1997) where varying N and P rates caused variation in capsule weight per plant, diameter of capsules, number of seeds per capsule, raceme length per plant and the general growth and development of different castor varieties. According to FAO (1998) the model predicting total yield can be utilized to identify optimum fertilization rates needed for a proper castor growth based on the available varieties. It can also be used in formulating suitable growth models to stimulate yields of castor and also in delineating areas with optimum agro climatic environments for achieving potential productivity castor. This is necessary because among various stages of crop growth, reproductive period translating into better and productive post harvest parameters as reported by Kaurobas *et al.* (1999) were observed to be the most critical as far as N and P rates are concerned not only in castor but also in many other oil crops like groundnut, soya beans, etc. Sufficient quantities of N and P during this stage limit the yield while adequate quantities increase the yields. Similarly Denovan and Landsberg (1999) confirmed that castor crop requires quantities of N and P not exceeding 120 kg N/ha and 15 kg P/ha. Lower doses than these ultimately result in significantly lesser yields.

Their studies also revealed that with management practices like fertilizer does, weeding and plant protection adequately maintained, higher seeds, raceme and capsule size and weight can be achieved. Higher yields, they added, are promoted through adequate development of these parameters that contribute maximally to yield of any castor variety. This is due to the dominant physiological characteristics, adequate N and P, soil conditions and congenial environmental conditions prevailing during the reproductive period like higher moisture availability, longer photo-period and optimum thermal regime.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Experimental Site

Field trials were conducted for three years during the wet seasons of 2006, 2007 and 2008 at the experimental farm of the Institute for Agricultural Research, Samaru-Zaria (11^0 11'N; Latitude 7^0 38,E Longitude 686m above sea level) in the Northern Guinea Savanna ecological zone of Nigeria.

A composite soil sample of the experimental site was taken from a depth of 0 – 30cm in each year and analyzed for physico-chemical properties using standard procedure as described by Black (1968) and Whingwiri *et al.* (1987). The temperature during the period of trials ranged from 12.5^0C to 35.1^0C while relative humidity range was 21.1 – 82.0% (Appendices I – III). In 2006 and 2007, the soil was found to be clay loam while the site of 2008 was sandy loam. In all the three years, the soils were characterized by low pH (4.8 – 5.7), low organic carbon (0.22 – 0.43%), low total N (0.035 – 0.088%), low to medium available P (2.56 – 9.44cmol/kg). Potassium was moderate (0.33 – 0.49cmolkg^{-1}) in all the three years. Results of the soil analyses are shown in Appendix IV.

3.2 Treatments and Experimental Design

The experimental treatments consisted of factorial combination of three levels of nitrogen (0, 60 and 120 kg N/ha), three levels of phosphorus (0, 7.92 and 15.84 kg P/ha) and four castor cultivars Ex-Brazil 1 and 2 and Ex-India 1 and 2. The 36 treatments were laid out in a split-plot design with nitrogen and phosphorus levels

combined and allocated to the main plots, while the four varieties were assigned to the subplots. The treatments were replicated three times each year.

3.2.1 Varietal description of castor seeds used

1. Ex-Brazil 1: The seeds whose colour ranged from black to dark brown, are encased in a spiny brittle outer shell that is compressed dorsally. They weigh between 2.8–3.8g. The plant is a tall, glabrous, annual reaching a height of between 1.0–1.5m. The leaves are dark green in colour and are broad, palmately seven to many lobed, serrated and borne alternatively. The oil content value ranged from 42–44% while the potential seed yield ranged in from 200–250 kg ha^{-1}.
2. Ex-Brazil 2: A black seeded variety with small seeds varying from oblong to smooth or mottled and can weigh between 0.5–1.1g. The plant can grow upto a height of between 0.9-1.2 m. The leaves are reddish green in colour, membranous, of about 30–60 cm in diameter and are lobed from oblong to linear. The racemes are stout and erect. Capsules are 1.5–2.5cm long and globosely oblong. The oil content value ranged from 45–48%, while the potential seed yield ranged from 190–230 kg ha^{-1}.
3. Ex-India 1: Seeds are small and variegated with dark brown stripes over the generally light brown colour. Seed weight ranged from 0.4–0.9g. The leaves are reddish green in colour. The flowers are borne in clusters. The plant can grow up to a height of between 0.8–1.1m. The oil content value ranged from 44–46% while the potential seed yield ranged between 180 – 220 kg ha^{-1}.

4. Ex-India 2: A whitish cream coloured big seed variegated with brownish stripes has its seed weight ranging from 1.5–2.5g. The seed shape resembles a huge tick engorged with blood. The tall glaborous plants can reach a height of between 1.0–1.3m. The leaves are green in colour. The capsules grow in clusters on spikes of the plant. Flowers are large in terminal sub-panicle racemes. The oil content value ranged from 42–44% while the potential seed yield value is from 170–210 kg ha^{-1}.

3.2.2 Plot size

The gross plot size consisted of six ridges each 0.75m wide and 5.0m long giving an area measuring 22.5m^2. The two outer rows on both sides were left as borders. Four inner rows constituted the net plot covering an area of 15.0 m^2. The two outermost rows, one on both sides of the net plot were used for destructive sampling. The remaining two rows were used to assess yield parameters.

3.3 Agronomic and Management Practices

3.3.1 Land preparation

In each year, the field was ploughed once and harrowed twice to a fine tilth. This was then followed by ridging at 75cm apart. The field was then marked out into treatments and replications. Half metre unplanted boarders were maintained between the plots, while one metre unplanted boarders were left between replications.

3.3.2 Seed dressing

The seeds of all the four castor varieties that were used in this study were dressed with Apron Star (methylthiuram + metalaxyl + carboxin) at the rate of 3.0kg of seed per 10g sachet of the chemical before planting.

3.3.3 Sowing

All seeds were sown manually at the rate of two seeds per hill at depths of about 5cm. Germination period of all seeds ranged between seven to ten days. Reseeding was done to fill un-germinated seeds at two weeks after sowing. The seedlings were thinned to one per stand four weeks after sowing. The intra and inter row spacing were maintained at 30 and 75cm, respectively. Planting was done on 29th/7/06. 12th/7/07, and 10th/7/08 in 2006, 2007 and 2008, respectively.

3.3.4 Fertilizer application

The whole of the P in the form of Single Super Phosphate SSP (18%P_2 O_5) was applied as per the treatments and incorporated at planting. Urea (46%N) was applied in two equal doses at two and six weeks after sowing according to the treatments as side dressing in narrow groves and then covered with soil. Potassium was not applied in all the three years. The soil analysis results indicated that the amount of K contained in the soil was adequate for proper growth and development of the four castor varieties used in this research study. This is because according to Daiz *et al.* (1992) the standard recommended dosage of K required for proper castor growth and yield ranges from 0.23 – 0.45 cmolkg^{-1}. Results of the soil analyses of the three sites in the three years of this research indicated that the soil contained a range of 0.33 – 0.49cmolkg^{-1}.of K.

3.3.5 Crop protection

To avoid the attack of any form of fungi, insects or bacteria, Sherpa Plus (Cypermethrin + dimethoate) at the rate of one litre per hectare along with Benlate (benomyl) and Dithane M45 (mancozeb) at one kilogram active ingredient per hectare were applied weekly starting from the fourth to the sixth week after sowing. This was

done also to control likely aphid infestation as well as rust and blight infections in all the three years.

3.3.6 Weed control

Weeds were controlled manually by hand hoeing at 2, 4 and 6 WAS in the experimental plots and around the discard area.

3.3.7 Harvesting and processing

The crops were harvested after they reached physiological maturity i.e. when 50% of the capsules showed sign of dryness and most leaves were shed off from the plants. The two innermost rows of the net plot were then harvested manually by cutting the plants at their base. The racemes were then separated from the plants and air dried at room temperature for several days. Shelling of the capsules was done by hand after removing capsules from the racemes to obtain the seeds.

3.4 Observations and Data Collection

3.4.1 Meteorological data

Data on the amount and distribution of rainfall, maximum, and minimum temperatures, and relative humidity at Samaru during the period of the experiment (2006, 2007 and 2008) were obtained from the Meteorological Unit, Institute for Agricultural Research, Samaru Zaria and are presented in Appendices I –III.

3.4.2 Assessment of growth characters

Assessment of growth characters in the three years except where otherwise slated was done periodically on five randomly tagged plants in each plot at 4, 8, 12 and 16 WAS during the crop growth period.

Plant establishment count: Plants that have established in the net plot at 3 WAS (before thinning) were counted and the number recorded.

Plant height (cm): Heights of the five tagged plants in each plots were measured using meter rule. The heights were measured from the ground level to the tip of the apical bud. The mean height was recorded.

Number of leaves per plant: This was done by counting the total number of leaves on the five tagged plants and the mean calculated and recorded.

Number of branches per plant: The numbers of branches on each of the five tagged plants were counted and the mean worked out and recorded.

Total dry matter (TDM) per plant (g): The total dry weight per plant was obtained each year from the mean of the five plants per plot at 4, 8, 12 and 16 WAS. The plants were cut from the base of the stems of the two border rows. These parts were then oven-dried at a temperature of 70^0C to a constant weight and the mean dry weight was recorded.

Leaf area index (LAI): This was determined by measuring the length and breadth of leaves from the five tagged plants from the widest portions of each leaf with a ruler. The product of length and breadth was then multiplied by a factor of 0.6817 (Chimanshette *et al*., 1991) from which the mean area of individual leaf of each sampled plant was obtained. The leaf area per plant was then multiplied by the number of plants/m^2 and was divided by the land area covered by the plants (Duncan, 1955 and Hasket, 1968).

$$\text{LAI} = \frac{\text{A}}{\text{P}} = \frac{Leaf\ area\ of\ plant}{Area\ subtended\ by\ plant}$$

Where: -

A = leaf area of plant (m^2)

P = Ground area of plant (m^2)

Crop growth rate (CGR): Five sampled plants from each net plot were oven dried at 70^0C to a constant weight at 4, 8, 12 and 16 WAS. The (CGR) expresses the dry matter increment of plant material per unit area of ground per unit time. Crop growth rate was computed using the formula by Watson (1958) and Little and Hills (1978).

$$\text{CRG} = \frac{w_2}{t_2} - \frac{w_1}{t_1} x \frac{1}{P} (gm^{-2} wk^{-1})$$

Where: -

W_2 = Dry matter weight at the second sampling period

W_1 = Dry matter weight at first sampling period

t_2 = Time at which w_2 was taken

t_1 = Time at which w_1 was taken

P = Land area

Wk = Week

Days to 50% first flowering: The duration in days from sowing to when 50% of the plant population in each net plot have flowered was computed and recorded.

Height to first capsule (cm): The height from the ground level to the first capsule of each of the five tagged plants was measured from each plot using a metre-rule and the mean height recorded.

Net assimilation rate (NAR): After the leaf area of each sampled plant and their dry weights were determined, their NAR's were also calculated using the formula suggested by Watson (1958):

$$NAR = \frac{W_2 - W_1}{T_2 - T_1} x \frac{Log_e A_2 - Log_e A_1}{A_2 - A_1} gcm^{-2} wk^{-1}$$

Where W_2 and W_1 represents total dry weight at time T_2 and T_1 respectively.

A1 and A2 are leaf area values for time $T_1$and T_2, respectively and Log_e represents natural logarithm.

3.5 Assessment of Yield Parameters

3.5.1 Capsule weight per plant (g)

This was determined by weighing the harvested capsules from the five tagged plants per plot and the mean recorded.

3.5.2 Diameter of capsule (cm)

The diameter of the capsules of five randomly selected capsules in each plot were measured using a vaneer caliper and the mean recorded.

3.5.3 Height to first raceme (cm)

This was measured using a tape on five randomly tagged plants and the mean length recorded.

3.5.4 100-seed weight (g)

From each net plot 100 seeds were counted and the mean weight recorded.

3.5.5 Number of capsules per raceme

This was determined on five randomly tagged plants per plot and the mean recorded each year.

3.5.6 Number of seeds per capsule

The number of seeds per capsule were determined by threshing and counting the seeds in each capsule of the five randomly tagged capsules and the mean recorded.

3.5.7 Number of racemes per plant

The numbers of racemes per each of the tagged plants were counted and the mean calculated and recorded.

3.5.8 Raceme length per plant (cm)

From each of the five tagged plants, the mean raceme length was determined and recorded.

3.5.9 Seed yield (kg/ha)

The harvested seeds from each net plot were dried, threshed and the seeds cleaned and weighed. The weights obtained were expressed in kilogram per hectare.

3.5.10 Oil content (%) of seeds

Hundred equal-sized seeds from each plot were picked and analyzed for oil content and viscosity using the AAOC (1995) method.

3.5.1 Plant tissue analysis

At 50% flowering, five fully matured leaves were randomly taken from each treatment. The leaves were thoroughly cleaned and oven-dried at 70^0C to a constant weight. They were then ground with a Wiley mill and passed through 40-mesh screen and preserved labelled polythene bags for chemical analysis as suggested by Pandey and Sinha (2006) to determine the contents of the following: -

Total nitrogen: This was determined by micro-kjeldahl distillation Procedure (IITA, 1975). The process involved the digestion of 0.5gm plant sample with concentrated H_2SO_4 using 5gm of kjeldahl catalyst mixture. Ten mls (10.0mls) of aliquot of the digest was measured to which 10mls of 10N NaoH was added. This was then distilled into boric acid indicator up to the 150ml mark. The distillate was titrated using 0.05N H_2SO_4 to a Pink end point. The percentage N in the plant sample was calculated using the formula below: -

$$N(\%) = \frac{0.014 \;\; x \;\; titre \;\; value \;\; x \;\; vol \;\; of \;\; digest \;\; x \;\; normality \;\; of \;\; acid}{weight \;\; of \;\; sample \;\; x \;\; volume \;\; of \;\; aliquot \;\; used} x \;\; 100$$

Percent concentration of P, K, Ca, Mg, Na & S in the leaves of castor: Per cent P was determined by the Vanado molybdate yellow colour of Bray and Kurtz (1945) as modified by Murphy and Riley (1962). The concentrations of K, Ca, Mg and Na were determined by atomic absorption spectrophotometry using Porking Elmer model 290B. Total sulphate in the sample was measured using a B and L spectronic – 70 as described by Tabatabai and Bremmer (1970).

3.6 Statistical Analysis of Data

Data were analyzed using the statistical analysis system procedure (SAS, 2003) and that of Snedecor and Cochran (1967). The data collected were processed through analysis of variance (ANOVA). The means were separated by Duncan's New Multiple Range Test (DMRT) at 0.05 level of statistical probability.

Path analysis as described by Williams *et al*. (1990) was performed. The direct, indirect and total contributions to yield were computed by separating correlation coefficient (r) into direct, indirect and total effects of the components of yield as described by Dewey and Lu (1959) and Wright (1960). The polynomial responses of

seed yield to the factors tested were determined through regression analysis as suggested by Steel and Torrie (1984).

CHAPTER FOUR

4.0 RESULTS

4.1 Growth Parameters

4.1.1 Stand count per plot at 3 WAS

Results from Table 4.1 show the effect of N and P on stand count per plot (7.5 m^2) at 3 WAS of four castor varieties in Samaru during 2006 – 2008 wet seasons. Plots supplied with 120 kg N/ha had significantly higher number of stands at 3 WAS in 2008 and the combined than 60 kg N/ha and the control which were at par with each other. In 2006 and 2007 however, 120 and 60 kg N/ha rates were at par with each other but only in 2007 was 60kg N/ha significantly higher than the control.

The application of P had significant effects in 2006, 2008 and the combined. The application of 15.84 kg P/ha resulted in significantly higher stands per plot than the control but was at par with 7.92 kg P/ha in 2008 and the combined. In 2006 however, the 15.84 kg P/ha was significantly higher than 7.92 kg P/ha which was at par with the control.

Plots with varieties Ex-Brazil 1 and 2 and Ex-India 1 had significantly higher stands/plot than Ex-India 2 in 2006 and 2007 but were at par with each other. In 2008 and the combined, plots planted to Ex-Brazil 1 had significantly higher stands/plot than those planted to Ex-Brazil 2 and Ex-India 1, which were at par with each other and higher than plots with Ex-India 2.

The interaction between N and P, N and variety and P and variety were significant at combined.

Result of interaction between N and P and N and variety in the combined as shown on Table 4.2 indicated that at constant 0 kg N/ha, increasing P levels above

Table 4.1: Effects of N and P on stand count at 3 WAS of four castor varieties at Samaru in 2006, 2007 and 2008 wet seasons and combined

Treatments	Stand count at 3 WAS at 7.5m^2 2006	2007	2008	Combined
Nitrogen (N) (kgha^{-1})				
0	24.81b	29.28b	28.94b	28.00b
60	27.00a	30.25ab	29.92b	28.73b
120	26.47a	31.72a	31.58a	29.93a
SE ±	0.62	0.72	0.58	0.64
Phosphorus (P) (kgha^{-1})				
0	25.14b	30.53	28.33b	28.00b
7.92	25.69b	31.25	30.78a	29.24a
15.84	27.44a	29.47	31.33a	29.42a
SE ±	0.62	0.72	0.58	0.64
Varieties (V)				
Ex-Brazil 1	29.00a	32.63a	34.89a	32.17a
Ex-Brazil 2	27.93a	32.85a	31.78b	30.85b
Ex-India 1	27.41a	32.37a	32.37b	30.72b
Ex- India 2	20.04b	23.82b	21.56c	21.80c
SE ±	0.62	0.72	0.58	0.64
Interaction				
N X P	NS	NS	NS	*
N X V	NS	NS	NS	*
P X V	NS	NS	NS	*
N X P X V	NS	NS	NS	NS

Means within a column of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT

WAS = Weeks after sowing

NS = Not significant

* = Significant at $P \leq 0.05$

0 kg P/ha caused a decrease in stands/plot at 3 WAS, however, at higher N rates each increase in P rates resulted in significant increase in stands/plot at 3 WAS. Holding P constant, it was observed that at 0 kg P/ha, an increase in N up to 60 kg N/ha significantly decrease the stands/plot but increasing N level up to 120 kg N/ha caused a significant increase that was statistically similar to that produced at 0 kg N/ha. At other higher P rates however, each increase in N rate significantly increase stands/plot. The highest stand count of 30.64 was produce with 15.84 kg P/ha with 120 kg N/ha, but it was comparable to that observed by combing 60kg N/ha with the two highest rate of P and 120kg N/ha with 7.92kg P/ha.

The interaction between N and castor varieties (Table 4.2) revealed that at 0 and 15.84 kg N/ha, Ex-Brazil 1 had the highest stand count/plot followed by Ex-India 1 while Ex-India 2 produced the least. At 60 and 120 kg N/ha, the Brazilian varieties produced the highest stands/plot with Ex-Brazil 1 having the highest stands/plot. The two Indian varieties produced statistically similar but lower stands/plot at the same N rates. Plots with Ex-Brazil 1 produced the highest stands/plot at 3 WAS when subjected to the highest N rate.

Results of interaction between P and variety (Table 4.3) showed that at 0 kg P/ha, the two Brazilian varieties produced statistically similar stands/plot whose result was similar to Ex-India 1, the least stands/plot was observed with plot having Ex-India 2. However, at 7.92kg P/ha, Ex-Brazil 2 and Ex-India 1 produced statistically similar stands/plot whose value was lower than Ex-Brazil 1 but higher than Ex-India 2.

It was observed that Ex-Brazil 1 produced statistically higher stands/plot when P rates were increased from 0 –7.92 kg P/ha, however, above this rate stands/plot did not

Table 4.2: Interaction between N and P and N and variety on stand count of four castor varieties at 3 WAS in combined years of 2006, 2007 and 2008 wet seasons at Samaru

Treatments	Stand count at 3 WAS at 7.5m^2 N rates (Kg ha^{-1})		
	0	**60**	**120**
P rates (Kg ha^{-1})			
0	28. 53 bcd	26.92 d	28.56 bc
7.92	27.00 cd	30.14 ab	30.58. a
15.84	28.47 cd	29.14 abc	30.64 a
SE+		0.58	
Varieties			
Ex – Brazil 1	29.52 de	33.04 ab	33.96 a
Ex – Brazil 2	29.04 ef	30.96. cd	32.56 abc
Ex – India 1	30.30 de	29.89 e	31.96 bcd
Ex – India 2	23.15 e	21.89 f	31.96 bcd
SE+		0.67	

Means within a column or row of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT.

Table 4.3: Interaction between P and variety on stand count of four castor varieties at 3 WAS in combined years of 2006,2007 and 2008 wet seasons at Samaru.

Treatments	Stand count at 3 WAS P rates (kgha^{-1})		
Varieties	0	7.92	15.84
Ex – Brazil1	30.52 bc	33.78 a	32.22 ab
Ex – Brazil 2	31.15 bc	30.04 c	31.37 bc
Ex – india1	30.07 c	30.30.c	31.81 bc
Ex – India 2	20.26 d	22.89 d	22.26 d
SE+	0.67		

Means within a column or row of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT.

significantly change. No significant changes were observed among all other varieties with all changes in P levels. Ex-Brazil 2 had significantly lower stands/plot when P rates were increased above 0 kg P/ha. However, at 15.84 kg P/ha, stands/plot produced were higher and similar statistically with those produced by the control plots. There was a significant increase in stands/plot produced by Ex-India 1 only when P level were raised above 7.92 kg P/ha while no significant difference was observed in stands/plot of Ex-India 2 when P rates were varied. Ex-Brazil 1 produced the highest stands/plot at 3 WAS with 15.84 kg P/ha.

4.1.2 Plant height

The effect of N and P rates on plant height of four castor varieties in 2006 rainy season is presented on Table 4.4; the results showed effects of N and P rates on plant height significant at all sampling periods. Each increase in the application of N and P resulted in significant increase in plant height at all sampling stages.

Amongst the varieties tested, Ex-Brazil 1 was consistently the tallest all sampling stages. Ex-India 2 was the shortest plant at 8, 12 and 16 WAS while Ex-Brazil 2 and Ex-India 1 had similar plant heights at 8, 12 and 16 WAS. The two Indian varieties produced shorter but similar plant heights at 4 WAS. The interaction between N with P and N with variety were significant on plant height at 16 WAS in 2006 (Table 4.5).

The interaction between N and P on plant height (Table 4.5) indicated that at each rate of P there was significant increase in plant height with each increase in rates of N. Similarly, at 60 and 120 kg N ha^{-1}, each increase in rate of P caused a significant increase in plant height. However, at 0 kg N ha^{-1}, only increase in P rate to 7.92 kg P ha^{-1} resulted to a significant increase in plant height, beyond this rate, there was no further significant increase. The tallest plants were obtained with a combination

Table 4.4: Effect of N and P rates on plant height of four castor varieties at Samaru in 2006 wet season

Treatments	Plant height (cm) 4 WAS	8 WAS	12 WAS	16 WAS
Nitrogen (N) ($kgha^{-1}$)				
0	16.50c	44.47c	52.84c	70.69c
60	27.00b	57.52b	68.33b	88.00b
120	33.00a	76.01a	112.07a	158.67a
SE ±	0.47	0.59	0.49	0.65
Phosphorus (P) ($kgha^{-1}$)				
0	18.19c	50.99c	60.56c	76.98c
7.92	27.03b	58.77b	77.89b	103.78b
15.84	31.28a	68.23a	94.81a	136.61a
SE ±	0.47	0.59	0.49	0.65
Varieties (V)				
Ex-Brazil 1	29.37a	64.26a	85.89a	113.52a
Ex-Brazil 2	26.30b	59.63b	81.13b	106.56b
Ex-India 1	23.74c	60.34b	78.96b	104.44b
Ex- India 2	22.59c	53.10c	65.02c	98.63c
SE ±	0.47	0.59	0.49	0.65
Interaction				
N X P	NS	NS	NS	*
N X V	NS	NS	NS	*
P X V	NS	NS	NS	NS
N X P X V	NS	NS	NS	NS

Means within any column of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT

WAS = Weeks after sowing

NS = Not significant

* = Significant at $P \leq 0.05$

of 15.84kg P and 120 kg N ha^{-1} while the control treatments produced the shortest plants.

The interaction between N rates and varieties on plant height at 16 WAS in 2006 (Table 4.5) revealed that each variety experienced a significant increase in plant height with each increase in N rates. At each fertilizer rate, Ex-Brazil 1 was taller than the other varieties tested, except at 120 kg N/ha when it was comparable to Ex-Brazil 2. Ex-India 1 was taller than Ex-India 2 except at 120kg N/ha when both were significantly similar

In 2007 N, P and varietal differences significantly influenced plant height of castor at all sampling stages (Table 4.6). Each increased application of N resulted in a significant increase plant height. Similarly, each increase P level caused a significant increase in plant height except at 4 WAS when 7.92 and 15.84 kg P ha^{-1} had statistically similar plant heights.

Amongst the varieties evaluated, Ex-Brazil 1 consistently gave the tallest plants comparable only to those of Ex-Brazil 2 at 12 and 16 WAS. Ex-Brazil 2 in turn was significantly taller than Ex-India 1 except at 8 and 16 WAS when they were statistically similar. Ex-India 1 produced taller plants than Ex-India 2 at all sampling stages except at 16 WAS when the difference was not significant. Only the interaction between N and P on plant height in 2007 at 16 WAS was significant.

Table 4.7 shows the interaction between N and P on plant height of castor at 16 WAS in 2007 wet season. There were no significant differences in castor plant height treated to various levels of P at constant 0 kg N/ha, however, plant height increased significantly with each increase in P rates at constant 60 kg N/ha while at 120 kg N/ha,

Table 4.5: Interaction between N and P and varieties and N on plant height of four castor varieties at 16 WAS in 2006

Treatment	Plant Height (cm)		
	N rates(Kgha^{-1})		
P rates (Kgha^{-1})	0	60	120
0	65.92g	79.43e	85.58d
7.92	72.83f	85.92d	152.58b
15.84	73.33f	98.67c	237.83a
SE ±		1.93	
Varieties (V)			
Ex-Brazil 1	75.56f	98.56d	166.44a
Ex-Brazil 2	70.11g	88.79e	160.78ab
Ex-India 1	71.00g	85.56e	156.78bc
Ex- India 2	66.11h	79.11f	150.67c
SE±		2.2.0	

Means within a column or row of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT.

Table 4.6: Effect of N and P rates on plant height of four castor varieties at Samaru in 2007 wet season

Treatments	Plant height (cm) 4 WAS	8 WAS	12 WAS	16 WAS
Nitrogen (N) ($kgha^{-1}$)				
0	18.00c	49.34c	57.50c	80.11c
60	23.86b	64.11b	77.59b	107.94b
120	34.85a	81.98a	119.12a	161.08a
SE ±	0.72	0.59	0.42	2.40
Phosphorus (P) ($kgha^{-1}$)				
0	20.92b	54.23c	67.25c	86.12c
7.92	27.08a	67.55b	87.84b	120.24b
15.84	28.71a	73.64a	99.12a	142.77a
SE ±	0.72	0.59	0.42	2.40
Varieties (V)				
Ex-Brazil 1	30.44a	73.72a	89.22a	129.56a
Ex-Brazil 2	26.83b	65.68b	87.30a	120.16ab
Ex-India 1	24.26c	63.63b	84.56b	111.30bc
Ex- India 2	20.74d	57.54c	77.97c	104.49c
SE ±	0.72	0.59	0.42	2.40
Interaction				
N X P	NS	NS	NS	*
N X V	NS	NS	NS	NS
P X V	NS	NS	NS	NS
N X P X V	NS	NS	NS	NS

Means within any column of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT

WAS = Weeks after sowing

NS = Not significant

* = Significant at $P \leq 0.05$

application of 7.92 kg P ha^{-1} significantly increased plant height above untreated control but a further increase in P caused no further significant increase in plant height.

Also at 7.92 and 15.84 kg P ha^{-1} each increase in N level caused a significant increase in plant height while at 0 kg P ha^{-1}, varying N rates did not significantly affect castor plant height. The combination of the highest rates of N and P produced the tallest plants whose value was statistically at par with that produced by the combination of 7.92 kg P ha^{-1} + 120 kg N ha^{-1}.

Plant height of castor at four sampling periods as affected by N, P and variety in 2008 rainy season is presented in Table 4.8. The result indicates that plant height was increased with each increase in quantities of N at all sampling periods. At 4WAS, application of 7.92 kg P ha^{-1} resulted in significant increase in plant height relative to the control beyond which plant height was depressed, but at other sampling periods, each increase in P rate significantly increased plant height.

Varietal effect on plant height (Table 4.8) indicates that Ex-Brazil 1 was significantly taller than all others at all stages of crop sampling. Variety Ex-Brazil 2 was next in height but comparable to Ex-India 1 at 8 and 16 WAS. Ex-India 2 was significantly shorter than all other varieties. The interaction was significant only between N and P and also between N and variety each at 16 WAS.

The interaction between N and P on plant height of castor at 16 WAS in 2008 wet season (Table 4.9) shows that at each level of P, significant increases in plant height were observed with each increase in rate of N. There was also a similar increase in plant height with each increase in P at constant 60 and 120 kg N ha^{-1}, however, at 0 kg

Table 4.7: Interaction between N and P on plant height of four castor varieties at 16 WAS in 2007

Treatment	Plant Height (cm)		
	N rates(Kgha^{-1})		
P rates (Kgha^{-1})	0	60	120
0	76.63d	87.83d	93.91cd
7.92	82.99d	111.10c	166.63a
15.84	80.69d	124.91b	173.25a
SE ±		1.93	

Means within a column or row of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT.

Table 4.8 Effects of N and P rates on plant height of four castor varieties at Samaru, 2008 wet season

Treatments	Plant height (cm) 4 WAS	8 WAS	12 WAS	16 WAS
Nitrogen (N) ($kgha^{-1}$)				
0	23.42c	44.47c	62.92c	88.17c
60	33.92b	57.52b	95.67b	117.16b
120	39.22a	76.01a	135.35a	182.64a
SE ±	0.50	0.59	0.64	0.50
Phosphorus (P) ($kgha^{-1}$)				
0	23.78b	50.99c	76.89c	97.58c
7.92	25.94a	58.77b	98.28b	136.03b
15.84	36.83b	68.23a	118.76a	154.36a
SE ±	0.50	0.59	0.64	0.50
Varieties (V)				
Ex-Brazil 1	35.93a	64.26a	107.44a	141.97a
Ex-Brazil 2	33.70b	59.63b	102.85b	132.17b
Ex-India 1	31.11c	60.34b	97.24c	124.74b
Ex- India 2	28.00d	53.10c	84.37d	118.41d
SE ±	0.50	0.59	0.64	0.50
Interaction				
N X P	NS	NS	NS	*
N X V	NS	NS	NS	*
P X V	NS	NS	NS	NS
N X P X V	NS	NS	NS	NS

Means within any column of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT

WAS = Weeks after sowing

NS = Not significant

***** = Significant at $P \leq 0.05$

N ha^{-1} change in levels of applied P had no significant effect on plant height. A combination of the highest rates of N and P

gave the tallest plants while 0 kg N ha^{-1} combined with the lowest P rate gave the shortest castor plants.

In the variety by nitrogen interaction (Table 4.9) significant increase in plant height of each castor variety was observed with each increase in N level. At 120kg N/ha, Ex-Brazil 1 gave the tallest plant followed by Ex-Brazil 2, which in turn was significantly taller than Ex-India 1. At 60kg N/ha, Ex-Brazil 1 still produced significantly taller plants than all other varieties. Ex-Brazil 2 was better than the India varieties which were comparable. At 0 nitrogen, the Brazilian varieties were comparable in height while Ex-Brazil 2 was comparable to Ex-India 1. The tallest plants were produced by Ex-Brazil 1 at 120 kg N ha^{-1} while the shortest were produced by Ex-India 2 at 0 kg N/ha

4.1.3 Number of leaves per plants

The effects of N, P and variety on number of leaves of castor in 2006 rainy season were significant at all sampling periods (Table 4.10). Each increase in N significantly increased number of leaves except at 4 WAS when only 120 kg N ha^{-1} increased number of leaves over the control. A similar trend was observed with P except at 8 WAS when application of 7.92 kg N ha^{-1} increased leaf number but beyond which the increase was not significant.

Variety Ex-Brazil 1 produced the highest number of leaves all through the four sampling periods but was comparable to Ex-India 1 at 12 WAS. This was following by Ex-Brazil 2 which produced similar number of leaves with Ex-India 1 at 8 WAS and beyond. Ex-India 2 produced the least number of leaves but was similar to Ex-India 1 at

Table 4.9 Interaction between N with P and N with variety on plant height of four castor varieties at 16 WAS, 2008 wet season.

Treatments	Plant Height (cm)		
	N rates($Kgha^{-1}$)		
P rates ($Kgha^{-1}$)	**0**	**60**	**120**
0	87.33g	97.50f	107.92e
7.92	89.93g	119.81d	198.33b
15.84	87.25g	134.17c	241.67a
SE ±		1.63	
Varieties (V)			
Ex-Brazil 1	94.24h	126.89e	204.78a
Ex-Brazil 2	89.44hi	120.52f	186.56b
Ex-India 1	88.33i	112.67g	173.22c
Ex- India 2	80.67j	108.56g	166.00d
SE±		1.88	

Means within a column or row of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT.

8 and 16 WAS. Interaction between N and P and also between N and variety were significant at 16 WAS.

The interaction between N and P on number of leaves per plant at 16 WAS in 2006 is presented in Table 4.11. At 0 kg P/ha, applying 60 kg N/ha had no effect on leaf number relative to control but a further increase in N caused an increase in leaf number that was significantly higher than the untreated control. However, at 7.92 kg P ha^{-1}, application of 120 kg N ha^{-1} significantly increased leaf production in castor above the lower rates of N. At 15.84 kg P/ha, each increase in N significantly increased leaf production. At 0 kg N/ha, varying P levels had no effect on castor leaf production but at 60 kg N/ha only application of up to 15.84 kg P ha^{-1} significantly increased leaf number. However, at 120 kg N ha^{-1} each increase in P rate led to a significant increase in leaf number. The combination of 120 kg N ha^{-1} and 15.84 kg P ha^{-1} produced the highest number of leaves while the untreated control gave the least leaf number.

The interaction between N and variety (Table 4.11) indicates that application of 120 kg N ha^{-1} to Ex-Brazil 1 produced the highest number of leaves while Ex-India 2 had the least number of leaves per plant at 0 kg N ha^{-1}. Each variety produced more leaves with each increase in N rate except Ex-India 2 which had increased leaf number only at 120 kg N ha^{-1}. At 0 kg N ha^{-1}, each change in variety had no effect on leaf production of castor. Also at 60 kg Nha^{-1}, the two Brazilian varieties had similar leaf counts just as the Ex-India 1 had with Ex-India 2, but Ex-Brazil 2 was smaller than Ex-India 1. However, at 120 kg N ha^{-1}, Ex-Brazil 2 and the Indian varieties had similar leaf numbers but each significantly lower than Ex-Brazil 1.

Table 4.10: Effect of N and P rates on number of leaves per plant of four castor varieties at Samaru, 2006 wet season

Treatments	Number of leaves par plant 4 WAS	8 WAS	12 WAS	16 WAS
Nitrogen (N) (kgha^{-1})				
0	4.83b	3.83c	5.28c	8.25c
60	5.08b	4.61b	7.14b	9.61b
120	5.61a	5.89a	9.28a	12.56a
SE ±	0.33	0.33	0.40	0.44
Phosphorus (P) (kgha^{-1})				
0	4.57c	3.97b	5.81c	8.58c
7.92	5.19b	5.03a	7.50b	9.86b
15.84	5.67a	5.33a	8.39a	11.97a
SE ±	0.31	0.33	0.40	0.44
Varieties (V)				
Ex-Brazil 1	6.07a	5.22a	7.81a	11.22a
Ex-Brazil 2	5.48b	4.89b	7.11bc	10.37b
Ex-India 1	4.96c	4.47bc	7.33ab	9.78bc
Ex- India 2	4.19d	4.33c	6.67c	9.19c
SE ±	0.33	0.33	0.40	0.44
Interaction				
N X P	NS	NS	NS	*
N X V	NS	NS	NS	*
P X V	NS	NS	NS	NS
N X P X V	NS	NS	NS	NS

Means within any column of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT

WAS = Weeks after sowing

NS = Not significant

* = Significant at $P \leq 0.05$

Table 4.11: Interaction between N and P rates and Varieties and N on number of leaves of four castor varieties at 16 WAS, 2006 wet season

Treatments	Number of leaves		
	N rates(Kgha^{-1})		
P rates (Kgha^{-1})	0	60	120
0	7.83d	8.67cd	9.25c
7.92	8.67cd	9.33c	11.58b
15.84	8.25cd	10.83b	16.83a
SE ±		0.40	
Varieties (V)			
Ex-Brazil 1	8.78fg	10.89cd	14.00a
Ex-Brazil 2	8.44fg	9.89de	12.78b
Ex-India 1	8.11fg	9.22ef	12.00b
Ex-India 2	7.67g	8.44fg	11.44bc
SE±		0.47	

Means within a column or row of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT.

As shown on Table 4.12, the effects of N, P and variety on number of castor leaves in 2007 were significant. With each increase in N and P there was an increase in number of leaves per plant except at 4 WAS with 60 and 120 kg N ha^{-1} where there was no statistical difference in number of leaves produced. A similar trend was observed on the response of number of leaves to P application except at 8 and 12 WAS when increasing P to 15.84 kg P ha^{-1} had no significant effect on number of leaves produced.

The varietal effects indicated that Ex – Brazil I produced plants with the highest numbers of leaves that were only comparable to Ex-Brazil 2 at 12 WAS. Ex-Brazil 2 had higher number of leaves than the two Indian varieties. Ex-India 2 produced the least number of leaves, per plant than all others except at 16 WAS when it was similar to Ex-India 1. Only N and P interaction on number of leaves per plant 16 WAS was significant.

The interaction between N and P on number of leaves per plant in 2007 (Table 4.13) showed that at each level of P each increase in N level caused a significant increase in leaf production. At 0 kg Nha^{-1} only an increase in P up-to 15.84 kg Pha^{-1} significantly increased leaf number over the control while at 120 kg N ha^{-1}, leaf number increases with application of 7.92 kg Pha^{-1} beyond which the increase was not significant. At 60 kg N ha^{-1} , each increase in P level significantly increased leaf number. Plants treated to highest levels of N and P had the highest number of leaves that were statistically similar with those treated to 7.92 kg P ha^{-1} + 120 kg N ha^{-1}.

The effects of N, P and variety on number of leaves at four sampling periods in 2008 rainy season are presented on Table 4.14. The result showed that with each increase in N rate, leaf count increases significantly at 12 and 16 weeks. At 4 WAS however, only an increase of up to 120 kg N ha^{-1} significantly increased leaf count over

Table 4.12: Effects of N and P rates on number of leaves per plant of four castor varieties at Samaru, 2007 wet season

Treatments	Number of leaves per plant 4 WAS	8 WAS	12 WAS	16 WAS
Nitrogen (N) ($kgha^{-1}$)				
0	5.00b	5.61c	6.94c	8.14c
60	5.56a	6.44b	9.06b	10.44b
120	5.83a	6.86a	9.86a	13.89a
SE ±	0.31	0.28	0.41	0.40
Phosphorus (P) ($kgha^{-1}$)				
0	5.03c	5.50b	7.47b	8.89c
7.92	5.47b	6.56a	9.11a	10.61b
15.84	5.89a	6.86a	9.28a	12.97a
SE ±	0.31	0.28	0.41	0.40
Varieties (V)				
Ex-Brazil 1	6.59a	7.30a	9.70a	12.11a
Ex-Brazil 2	5.74b	6.81b	9.22a	11.19b
Ex-India 1	5.11c	5.96c	8.44b	10.30c
Ex- India 2	4.41d	5.15d	7.11c	9.70c
SE ±	0.31	0.28	0.41	0.40
Interaction				
N X P	NS	NS	NS	*
N X V	NS	NS	NS	NS
P X V	NS	NS	NS	NS
N X P X V	NS	NS	NS	NS

Means within any column of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT

WAS = Weeks after sowing

NS = Not significant

* = Significant at $P \leq 0.05$

Table 4.13: Interaction between N and P on number of leaves of four castor varieties at 16 WAS, 2007 wet season.

Treatments P rates ($Kgha^{-1}$)	N rates($Kgha^{-1}$) 0	60	120
0	7.50e	9.33d	9.83c
7.92	8.33e	10.17c	13.33a
15.84	8.58d	11.83b	13.67a
SE ±		0.38	

Means within a column or row of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT.

the control, and at 8 WAS, 60 and 120 kg N ha^{-1} gave comparable leaf count but each significantly higher than the control. Each increase in P level caused a significant increase in leaf counts at 8 and 16 WAS. At 4 WAS, each application of 7.92 kg P ha^{-1} did not result in significant change in leaf count over the control but at 15.84 kg P ha^{-1}, there was a significant reduction in leaf number. At 12 WAS the untreated control produced fewer leaf count than the other two P rates which were statistically similar.

The effect of variety showed that Ex-Brazil I had the highest leaf count at all sampling stages that was comparable with Ex-Brazil 2 at 8 and 16 WAS. Ex-Brazil 2 produced similar number of leaves with Ex-India I except at 12 WAS when the latter gave significantly lower leaf number. Ex-India 2 produced significantly lower leaf count than Ex-India 1 except at 4 and 16 WAS when they had comparable result. The interactions between N and P and also between N and variety were significant at the 16^{th} week of crop sampling.

The interaction between N and P on number of leaves per plant in 2008 rainy season (Table 4.15) showed that at each P level, increase in N rate caused a significant increase in number of leaves produced such that the highest P and the highest N rate combined gave the highest number of leaves.

At 0 kg N ha^{-1}, applying 7.92 kg P ha^{-1} significantly increased leaf count over the control beyond which a further increase had no such marked effect. At 60 kg N ha^{-1} only the application of 15.84 kg P ha^{-1} significantly increase leaf production over the control, while at 120 kg ha^{-1}, each increase in P level significantly increased leaf count.

The interaction between N rate and variety used in this experiment (Table 4.15) showed that each variety experienced an increase in leaf

Table 4.14: Effects of N and P rates on number of leaves per plant of four castor varieties at Samaru, 2008 wet season

Treatments	Number of leaves per plant 4 WAS	8 WAS	12 WAS	16 WAS
Nitrogen (N) ($kgha^{-1}$)				
0	5.17b	6.08b	7.61c	8.81c
60	5.58ab	6.78a	9.31b	10.94b
120	5.89a	6.97a	10.47a	16.06a
SE ±	0.44	0.34	0.32	0.34
Phosphorus (P) ($Kgha^{-1}$)				
0	5.83a	6.06c	7.69b	10.00c
7.92	5.72a	6.61b	9.81a	11.19b
15.84	5.08b	7.17a	9.89a	14.61a
SE ±	0.44	0.34	0.32	0.34
Varieties (V)				
Ex-Brazil 1	6.37a	7.44a	10.30a	12.74a
Ex-Brazil 2	5.56b	7.07ab	9.41b	12.11ab
Ex-India 1	5.41bc	6.67b	8.85c	11.74bc
Ex- India 2	4.85c	5.26c	7.96d	11.15c
SE ±	0.44	0.34	0.32	0.34
Interaction				
N X P	NS	NS	NS	*
N X V	NS	NS	NS	*
P X V	NS	NS	NS	NS
N X P X V	NS	NS	NS	NS

Means within any column of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT

WAS = Weeks after sowing

NS = Not significant

* = Significant at $P \leq 0.05$

number with each increase in N. With Ex–Brazil I giving the highest leaf number per plant when treated to 120 kg N ha^{-1}.

Varieties based on origin, each at 0 and 60 kg N ha^{-1} had statistically similar leaf count. However, at 120kg N ha^{-1} only the Indian varieties had similar leaf count.

4.1.4 Number of branches per plant

The effects of N and P on number of branches per plant of four castor varieties analyzed at four sampling periods in 2006 rainy season is presented in Table 4.16. Increased in N rates caused significant increases in number of branches per plant except at 4 WAS when 60 kg Nha^{-1} produced more branches than 120 kg Nha^{-1} and when at 12 WAS when 0 and 60 kg Nha^{-1} gave comparable number of branches but each significantly lower than 120kg Nha^{-1}. Similarly each increase in P rate caused a significant increase in number of branches except at 12 WAS when varying P rates had no effect on the crop. The varietal effect on number branches showed that Ex-Brazil I had the highest number of branches at 4 and 16 WAS, but did not differ significantly from Ex-Brazil 2 and Ex-India 1 at 8 WAS and the Indian varieties at 12 WAS Except at 12 WAS, Ex–India 2 had the least number of branches at each sampling period. The interaction between N and P at the 16 WAS was significant during the trial in 2006.

The interaction between N and P (Table 4.17) indicated that at 0 P ha^{-1}, only 120 kg Nha^{-1} caused a significant increase in number of branches per plant compared with the untreated control (0 kg Nha^{-1}) while at 7.92 kg P ha-$^{-1}$, the lower N rate had similar number of branches but each lower than 120 kg N ha^{-1}.

Table 4.15: Interaction between N and P and varieties and N on number of leaves of four castor varieties at 16 WAS, 2008 wet season.

Treatments	Number of leaves per plant		
	N rates(Kgha^{-1})		
	0	60	120
P rates (Kgha^{-1})			
0	8.25f	10.17d	11.58c
7.92	8.67e	10.67d	14.25b
15.84	9.50e	12.00c	22.23a
SE ±		0.34	
Varieties (V)			
Ex-Brazil 1	8.67hi	11.67de	16.00a
Ex-Brazil 2	8.33ij	10.67ef	14.56b
Ex-India 1	7.89j	10.00fg	13.00c
Ex- India 2	7.67j	9.44gh	12.00cd
SE±		0.39	

Means within a column or row of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT.

Table 4.16: Effects of N and P rates on number of branches per plant of four castor varieties at Samaru, 2006 wet season

Treatments	Number of branches per plant 4 WAS	8 WAS	12 WAS	16 WAS
Nitrogen (N) ($kgha^{-1}$)				
0	4.83c	3.86c	4.86b	8.25c
60	5.64a	4.67b	6.33b	9.64b
120	5.22b	6.08a	7.97a	12.78a
SE ±	0.31	0.34	1.25	0.40
Phosphorus (P) ($kgha^{-1}$)				
0	4.67c	4.06c	5.69a	8.56c
7.92	5.25b	4.97b	6.31a	9.94b
15.84	5.78a	5.58a	7.17a	12.17a
SE ±	0.31	0.34	1.25	0.40
Varieties (V)				
Ex-Brazil 1	6.15a	5.04a	6.11ab	11.41a
Ex-Brazil 2	5.59b	5.04a	5.00b	10.41b
Ex-India 1	4.96c	4.85ab	7.26a	9.93b
Ex- India 2	4.22d	4.56b	7.19a	9.15c
SE ±	0.31	0.34	1.25	0.40
Interaction				
N X P	NS	NS	NS	*
N X V	NS	NS	NS	NS
P X V	NS	NS	NS	NS
N X P X V	NS	NS	NS	NS

Means within any column of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT

WAS = Weeks after sowing

NS = Not significant

* = Significant at $P \leq 0.05$

Table 4.17: Interaction between N and P on number of branches per plant of four castor varieties at 16 WAS, 2006 wet season.

Treatment	Number of branches per plant		
	N rates(Kgha^{-1})		
P rates (Kgha^{-1})	0	60	120
0	7.83d	8.50cd	9.33c
7.92	8.67cd	9.42c	11.75b
15.84	8.25cd	11.00b	17.25a
SE ±		0.37	

Means within a column or row of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT.

At highest level of P, each increase in N rate caused a significant increase in number of branches per plant such that the combination of 120 kg N ha^{-1} and 15.84 kg P ha^{-1} gave the highest number branches, the reverse was the case with the plants in the plots with neither N nor P.

In 2007, as shown in Table 4.18, the number of branches per plant increased significantly with each increase in N except at 4 WAS when 60 and 120 kg Nha^{-1} produced statistically similar number of branches but each higher than the control, and at 12 WAS when the crop did not respond to the application of N. There was a significant increase in number of branches per plant with each increase in P level at 4, 8 and 16 WAS, the response to P at 12 WAS was not significant.

Amongst the varieties evaluated, Ex – Brazil I produced significantly higher number of branches than all other varieties except at 12 WAS when it produced the least. Also Ex – Brazil 2 at 12 WAS produced higher number of branches that was comparable to Ex – India 1 and 2 which were higher than Ex-Brazil 1.

The interaction between N and P on number of branches at 16 WAS in 2007 was significant (Table 4.19).Irrespective of P levels each increase in N rate caused an increase in number of branches per plant. Similarly, irrespective of N level, each increase in P rate caused a significant increase in number of branches per plant except at 0 kg Nha^{-1} when the two higher rates of P had comparable number of branches and each higher than the untreated control. The highest number of leaves was produced with 120 kg N + 15.84 kg P ha^{-1} while the least number was produced where neither N nor P was applied.

Table 4.18: Effects of N and P rates on number of branches per plant of four castor varieties at Samaru, 2007 wet season

Treatments	Number of branches per plant 4 WAS	8 WAS	12 WAS	16 WAS
Nitrogen (N) (kgha^{-1})				
0	4.94b	5.61c	6.03a	8.14c
60	5.83a	6.69b	6.81a	10.58b
120	5.69a	7.17a	6.94a	14.08a
SE ±	0.30	0.28	1.32	0.38
Phosphorus (P) (Kgha^{-1})				
0	5.00c	5.58c	5.64a	8.81c
7.92	5.50b	6.69b	6.97a	10.81b
15.84	5.97a	7.19a	7.17a	13.19a
SE ±	0.30	0.28	1.32	0.38
Varieties (V)				
Ex-Brazil 1	6.67a	7.63a	5.00b	12.37a
Ex-Brazil 2	5.81b	6.93b	7.63a	11.26b
Ex-India 1	5.04c	6.22c	7.67a	10.26c
Ex- India 2	4.44d	5.19d	6.07ab	9.85c
SE ±	0.30	0.28	1.32	0.38
Interaction				
N X P	NS	NS	NS	*
N X V	NS	NS	NS	NS
P X V	NS	NS	NS	NS
N X P X V	NS	NS	NS	NS

Means within any column of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT

WAS = Weeks after sowing

NS = Not significant

* = Significant at $P \leq 0.05$

Table 4.19: Interaction between N and P on number of branches of four castor varieties at 16 WAS, 2007 wet season.

Treatment	Number of branches per plant		
	N rates(Kg ha^{-1})		
P rates (Kgha^{-1})	0	60	120
0	7.81g	9.33e	10.17d
7.92	8.56f	10.14d	13.33b
15.84	8.78ef	11.69c	19.67a
SE ±		0.21	

Means within a column or row of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT.

The effect of N, P and variety of number of branches per plant in 2008 rainy season as presented on Table 4.20 showed that at 4 and 8 WAS applying 60 kg Nha^{-1} caused a significant increase in number of branches per plant over the control but further increase in N rate did not increase the number of branches. However, at 12 and 16 WAS each increase in N rate caused a significant increase in number of branches per plant. Applying 7.92 and 15.84 kg Pha^{-1} at 4 and 12 WAS produced statistically similar number branches per plant but each higher than the untreated control. However, at 8 and 16 WAS, each increase in the rate of P resulted in a significant increase in number of branches per plant. The effect of variety on number branches showed that Ex – Brazil I produced the highest number of branches at all sampling periods. It had statistically similar number of branches with Ex-Brazil 2 and Ex-India I at 8 WAS and Ex-Brazil 2 at 16 WAS. Ex-Brazil 2 and Ex-India I had similar number of branches per plant at all sampling stages except at 16 WAS while Ex-India 2 had the least number of branches at all crop stages except at 16 WAS when it was comparable to Ex-India 1. First order of interaction between N and P at 16 WAS was the only significant interaction in 2008 rainy season.

Interaction between N and P in Table 4.21 revealed that at 7.92 and 15.84 kg P $ha^{-1,}$ the number of branches increased significantly with each increase in levels of N. At 0 kg Pha^{-1}, applying 60 kg Nha^{-1} caused a significant increase in number of branches over the control, but a further increase had no such marked effect.

At 0 kg N ha^{-1}, increase in P level resulted in no significant increase in number of branches per plant, however, at 120 kg N ha^{-1} each increase in P level markedly increased the number of branches.

Table 4.20: Effects of N and P rates on number of branches per plant of four castor varieties at Samaru, 2008 wet season

Treatments	Number of branches per plant 4 WAS	8 WAS	12 WAS	16 WAS
Nitrogen (N) (kgha^{-1})				
0	5.22b	6.14b	7.61c	8.75c
40	5.83a	6.69a	9.42b	10.94b
80	6.03a	6.97a	10.58a	16.31a
SE ±	0.42	0.38	0.36	0.34
Phosphorus (P) (kgha^{-1})				
0	5.11b	6.03c	7.69b	9.94c
7.92	5.94a	6.61b	9.89a	11.28b
15.84	6.03a	7.17a	10.03a	14.78a
SE ±	0.42	0.38	0.36	0.34
Varieties (V)				
Ex-Brazil 1	6.78a	7.30a	10.48a	12.89a
Ex-Brazil 2	5.67b	7.11a	9.44b	12.26ab
Ex-India 1	5.44b	6.81a	8.93b	11.70bc
Ex- India 2	4.89c	5.19b	7.96c	11.15c
SE ±	0.42	0.38	0.36	0.34
Interaction				
N X P	NS	NS	NS	*
N X V	NS	NS	NS	NS
P X V	NS	NS	NS	NS
N X P X V	NS	NS	NS	NS

Means within any column of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT

WAS = Weeks after sowing

NS = Not significant

* = Significant at $P \leq 0.05$

Table 4.21: Interaction between N and P on number of branches of four castor varieties at 16 WAS, 2008 wet season

Treatment	Number of branches per Plant		
	N rates ($Kgha^{-1}$)		
P rates ($Kgha^{-1}$)	0	60	120
0	8.08ef	10.17cd	11.58c
7.92	8.67ef	10.58d	14.58b
15.84	9.50de	12.08c	22.75a
SE ±		0.34	

Means within a column or row of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT.

The highest number of leaves was produced with the highest combination of N and P while the least number was recorded for treatments with neither N nor P.

4.1.5 Total dry matter per plant (TDM)

The mean TDM per plant of the four castor varieties as influenced by N and P rates at all sampling periods in 2006 as presented in Table 4.22 showed that every increase in applied N led to a significant increase in plant dry weight. A similar trend was observed with each increase in P rate at all sampling periods.

Effect of varieties on TDM showed that Ex-Brazil 1 produced the heaviest plants at all cropping stages. This was followed by Ex-Brazil 2 which produced statistically similar plant dry weight with Ex-India 1 only at 4 and 8 WAS while Ex-India 2 gave the least TDM compared to all varieties at each sampling stage.

First order of interaction between N and P, N and variety and P and Variety at 16 WAS were significant.

The interaction between N and P (Table 4.23) showed that at each P level, increasing each level of N significantly increased the TDM weight of castor plants in 2006. This same trend was observed at 60 and 120 kg N ha^{-1}, when their P rates were varied. At 0 kg N ha^{-1}, however, there was no marked effect when the P levels were varied.

Total dry water weight of plant was at its highest value when the plants were subjected to the combination of 120 kg N + 15.84 kg P ha^{-1} while the least TDM weight was recorded in the untreated control.

Table 4.22: Effects of N and P rates on total dry matter per plant of four castor varieties at Samaru in 2006 wet season

Treatment	Total dry matter per plant (gm) 4 WAS	8 WAS	12 WAS	16 WAS
Nitrogen (N) ($kgha^{-1}$)				
0	0.57c	3.34c	9.60c	11.73c
60	1.12b	5.66b	17.16b	18.05b
120	1.86a	9.19a	26.23a	34.96a
SE ±	0.18	0.21	0.37	0.21
Phosphorus (P) ($kgha^{-1}$)				
0	0.79c	4.37c	12.49c	13.75c
7.92	1.20b	6.22b	17.74b	22.37b
15.84	1.56a	7.59a	22.76a	28.62a
SE ±	0.18	0.21	0.37	0.21
Varieties (V)				
Ex-Brazil 1	1.46a	6.69a	21.67a	23.43a
Ex-Brazil 2	1.22b	6.18b	17.95b	22.14b
Ex-India 1	1.12b	6.29b	16.53c	21.23c
Ex- India 2	0.94c	5.08c	14.49d	19.52d
SE ±	0.18	0.21	0.37	0.21
Interaction				
N X P	NS	NS	NS	*
N X V	NS	NS	NS	*
P X V	NS	NS	NS	*
N X P X V	NS	NS	NS	NS

Means within any column of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DNMRT

WAS = Weeks after sowing

NS = Not significant

* = Significant at $P \leq 0.05$

The interaction between N and variety is shown in Table 4.23. Irrespective of variety, there was a significant increase in TDM with each increase in N rate. Ex-brazil 1 at each N rate gave the highest TDM weight but was comparable to Ex-brazil 2 in the untreated control. Similarly, Ex-India 1 produced heavier TDM than Ex-India 2 except at 0 kg N ha^{-1} when they were comparable. The Ex-Brazil 2 variety did better than the Indian varieties except at 0 and 60 kg N ha^{-1} when it was statistically similar to Ex-India 1. Ex-Brazil 1 at 120 kg N ha^{-1} produced the highest TDM weight while Ex-India 2 at 0 kg N ha^{-1} gave the least.

The interaction between P and variety at 16 WAS in 2006 (Table 4.24) produced significant increases in TDM weight of each variety with each increase in P rate. At each P level, Ex-Brazil 1 produced significantly highest TDM per plant than others except at 0 kg P ha^{-1} when it was statistically similar to Ex-Brazil 2. Similarly, Ex-Brazil 2 produced heavier TDM than the other varieties except at 7.92 kg P ha^{-1} when it was similar to Ex-India 1. Ex-India 2 produced the least TDM relative to all other varieties but was comparable to Ex-India 1 at 0 kg P ha^{-1}.

The effect of N, P and variety on TDM per plant of castor in 2007 (Table 4.25) showed a significant increase in TDM per plant with increase in N levels in all sampling periods in 2007. Similarly, the same effect was recorded for each increase in P rates in all the sampling periods in 2007.

Table 4.23: Interaction between N and P and varieties and N on total dry matter per plant of four castor varieties at 16 WAS, 2006 wet season.

Treatment	Total dry matter per plant (gm)		
		N rates(Kgha^{-1})	
P rates (Kgha^{-1})	0	60	120
0	10.63f	13.85e	16.78d
7.92	11.97f	16.02d	39.13b
15.84	12.59f	24.28c	48.98a
SE±		0.28	
Varieties			
Ex – Brazil 1	12.52h	19.34e	38.41 a
Ex – Brazil 2	11.92hi	18.53f	35.96 b
Ex – India 1	11.50iJ	18.03f	34.17c
Ex – India 2	10.97J	16.29g	31.31d
S±		0.32	

Means within a column or row of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT.

Table 4.24: Interaction between P and varieties on total dry matter per plant of four castor varieties at 16 WAS, 2006 wet season at Samaru.

Treatment	Total dry matter per plant (gm)		
	P rates (kg ha^{1-})		
Varieties	O	7.92	15.84
Ex – Brazil 1	15.04h	24.09e	31.14a
Ex – Brazil 2	14.17h	22.82f	29.42a
Ex – india1	13.22i	22.06f	28.42b
Ex – India 2	12.57i	20.51g	25.49d
SE±		0.32i	

Means within a column or row of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT.

The differences in TDM weight amongst the four castor varieties at 12 WAS was not significant. At all other sampling periods, Ex-Brazil 1 produced the highest dry weight followed by Ex-Brazil 2 which in turn was comparable only to Ex-India 1 at 8 WAS. Ex-India 2 gave the least TDM which was comparable to Ex-India 1 only at 16 WAS. A significant interaction existed between N and P and also N and variety only at 16 WAS.

In the interaction between N and P (Table 4.26) there was no statistically significant variation in TDM weight of castor with change in P level under 0 N kg ha^{-1}. However, at each higher level of applied N, increase in various rates of P resulted in significant increases in TDM. In plants treated to 0 kg P ha^{-1}, only the application of 120 kg N ha^{-1} caused a difference in TDM weight above the control. However, at higher rates of P, each increase in N rate applied significantly increased TDM. Consistently, the combination of 120 g N + 15.84 kg P ha^{-1} gave rise to the production of the heaviest plants while plants that received neither N nor P application produced the lightest TDM.

The interaction between N and variety on TDM of plants in 2007 (Table 4.26) indicated that for each variety, the TDM weight of plant increased with each increase in N rate. Ex-Brazil 1 produced the heaviest plants at 120 kg N ha^{-1} that was comparable only to Ex-Brazil 2 at the same N rate. At each N level, each variety had a similar TDM weight to its counterpart. Ex-India 2 gave the least weight at each N rate but was comparable to all varieties at 60 kg N ha^{-1} and Ex-Brazil 2 at 120 kg N ha^{-1}.

Table 4.27 showed the effect of N, P and variety on plant TDM weight of castor in 2008 wet season. Application of N resulted in a significant increase in TDM in all

sampling periods. Similarly, there was a significant increase in TDM of plant with each increased P rates across all sampling periods.

Table 4.25: Effect of N and P rates on total dry matter per plant of four castor varieties at Samaru, 2007 wet season

Treatments	Total dry matter per plant (gm) 4 WAS	8 WAS	12 WAS	16 WAS
Nitrogen (N) ($kgha^{-1}$)				
0	0.73c	5.04c	12.11c	17.35c
60	1.35b	6.58b	18.69b	21.93b
120	2.13a	9.37a	35.51a	44.37a
SE ±	0.17	0.18	1.14	0.34
Phosphorus (P) ($kgha^{-1}$)				
0	0.98c	5.81c	15.62c	18.45c
7.92	1.48b	6.87b	20.64b	26.85b
15.84	1.78a	8.31a	30.04a	38.36a
SE ±	0.17	0.18	1.14	0.34
Varieties (V)				
Ex-Brazil 1	1.83a	7.61a	22.59	29.32a
Ex-Brazil 2	1.53b	7.25b	21.60	28.64b
Ex-India 1	1.22c	7.18b	21.17	26.73c
Ex- India 2	1.04d	5.94c	23.05	26.35c
SE ±	0.17	0.18	1.14	0.34
Interaction				
N X P	NS	NS	NS	*
N X V	NS	NS	NS	*
P X V	NS	NS	NS	NS
N X P X V	NS	NS	NS	NS

Means within any column of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT

WAS = Weeks after sowing

NS = Not significant

* = Significant at $P \leq 0.05$

Table 4.26: Interaction between N and P and varieties and N on total dry matter per plant of four castor varieties at 16 WAS, 2007 wet season.

Treatments	Total dry matter per plant (gm)		
		N rates(Kgha^{-1})	
P rates (Kgha^{-1})	0	60	120
0	15.16f	18.59def	19.87de
7.92	16.42ef	20.71d	40.61b
15.84	17.28edf	25.93c	64.43a
SE±		1.20	
Varieties			
E x – Brazil 1	18.45de	23.94c	47.03a
Ex – Brazil 2	17.91de	22.46c	45.57ab
Ex – india 1	16.90def	20.97cd	42.32b
Ex – India 2	16.12f	20.37cde	42.57b
SE±		1.38	

Means within a column or row of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DNMRT.

Ex-Brazil I consistently gave the heaviest plant TDM that was only comparable to Ex-Brazil 2 and Ex-India 1 at 8 WAS. Ex-Brazil 2 produced the next heavier plant TDM that was statistically similar to Ex-India 1 at 12 and 16 WAS. The least plant TDM weight was produced by Ex-India 2 at week 4.

Interaction between N and P and also between N and variety on TDM of plant in 2008 wet season (Table 4.28) were significant at 16 WAS. All different rates of N experience dry weight increases with each increase in P rate except at 0 kg N ha^{-1} when applying P at various rates had no effect on dry weight of plant. At 0 kg P ha^{-1} application of 60 kg N ha^{-1} caused a significant increase in TDM but increasing level of N further had no significant effect. However, at 7.92 and 15.84 P ha^{-1} each increase in rate or N caused a significant increase in plant TDM. The highest rates of N and P gave the heaviest TDM while the control gave the least.

The result of interaction between N and variety (Table 4.28) showed that with each variety, increase in rates of N significantly increased TDM production. At 0 kg N ha^{-1}, the two Brazilian varieties had similar plant dry weight while Ex-India 2 had the least TDM that was comparable only to Ex-India 1

. At 60 kg N ha^{1}, the two Brazilian varieties and Ex-India 1 had statistically similar plant TDM that was statistically higher than Ex-India 2 while at 120 kg N ha^{-1}, Ex-Brazil 1 had the heaviest TDM, followed by Ex-Brazil 2 and Ex-India 1 which were comparable.

Table 4.27: Effects of N and P rates on total dry matter per plant of four castor varieties at Samaru, 2008 wet season

Treatments	Total matter per plant (gm) 4 WAS	8 WAS	12 WAS	16 WAS
Nitrogen (N) ($kgha^{-1}$)				
0	0.88c	5.34c	12.62c	19.79c
60	1.78b	7.27b	24.33b	25.24b
120	2.79a	10.76a	36.24a	45.58a
SE ±	0.15	0.29	0.47	0.32
Phosphorus (N) ($kgha^{-1}$)				
0	1.17c	6.27c	16.08c	21.42c
7.92	1.98b	7.95b	23.77b	28.53b
15.84	2.29a	9.34a	33.34a	40.67a
SE ±	0.15	0.29	0.47	0.32
Varieties (V)				
Ex-Brazil 1	2.21a	8.26a	26.90a	32.38a
Ex-Brazil 2	1.97b	8.09a	24.84b	30.14b
Ex-India 1	1.67c	8.09a	24.01b	29.92b
Ex- India 2	1.41d	6.97b	21.84c	28.37c
SE ±	0.15	0.29	0.47	0.32
Interaction				
N X P	NS	NS	NS	*
N X V	NS	NS	NS	*
P X V	NS	NS	NS	NS
N X P X V	NS	NS	NS	NS

Means within any column of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT

WAS = Weeks after sowing

NS = Not significant

* = Significant at $P \leq 0.05$

Table 4.28: Interaction between N and P and varieties and N on total dry matter per plant of four castor varieties at 16 WAS, 2008 wet season at Samaru.

Treatments	Total dry matter per plant (gm)		
		N rates(Kgha^{-1})	
P rates (Kgha^{-1})	0	60	120
0	18.68f	22.15e	23.43de
7.92	19.88f	19.58d	41.11b
15.84	20.81f	29.00c	72.19a
SE±		0.51	
Varieties			
Ex – Brazil 1	20.70f	26.53d	49.90a
Ex – Brazil 2	20.26f	25.62de	44.56b
Ex – India 1	19.54fg	24.88de	45.34b
Ex – India 2	18.66g	23.94e	42.51c
SE±		0.59	

Means within a column or row of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT.

4.1.6 Crop growth rate (CGR)

The effect of N and P on CGR of four castor varieties in 2006 rainy season is presented in Table 4.29. The result shows that the effect of N was significant and CGR increased with each increase in levels of N. A similar trend was observed with each increase in P rates at all the cropping stages.

Varietal effect on CGR indicated that Ex- Brazil I had the highest CGR value that was comparable to Ex-Brazil 2 and Ex- India I at 8 and 12 WAS. At 16 WAS, Ex-India I also had a statistically similar CGR with Ex-Brazil 2. Ex- India 2 had the least CGR at all the sampling periods. The first order of interaction was significantly between N and P and also between N and variety at 16 WAS.

The interaction between N and P on CGR of four castor varieties in 2006 rainy season (Table 4.30) revealed that at 0 kg P ha^{-1}, only an increase in N of 120kg Nha^{-1} caused a significant increase in CGR over the control, however, at other higher P rates, each increase in N rate led to significant increase in CGR. Varying P rates, at 0 kg N ha^{-1} did not influence any change in CGR.

At 60 kg Nha^{-1}, increase in P level up to 7.92 kg $^{-1}$ caused a significant increase in CGR beyond which no marked effect was recorded while at 120 kg N ha^{-1}, each increase in P level resulted to a significant increase in CGR. The highest rate of N and P combined produced the highest CGR and vice versa.

The interaction between N and varieties (Table 4.30) showed that respective of variety, there was an increase in CGR with each increase in N rate. At 0 and 120 kg N ha^{-1}, there was no statistical variation in CRG amongst all the varieties evaluated. Ex-Brazil 1 and 2 and also Ex-India 1 had statistically similar CGR at 60 kg N ha^{-1}. Ex-India

Table 4.29: Effects of N and P rates on crop growth rate (CGR) of four castor varieties at Samaru, 2006 wet season

Treatments	Crop growth rate (g/plant/wk) 8 WAS	12 WAS	16 WAS
Nitrogen (N) ($kgha^{-1}$)			
0	4.23c	2.05c	1.45c
40	7.15b	3.44b	2.26b
80	11.35a	5.46a	3.60a
SE ±	0.28	0.28	0.25
Phosphorus (P) ($kgha^{-1}$)			
0	5.40c	2.61c	1.84c
7.92	7.80b	3.82b	2.46b
15.84	9.52a	4.52a	3.00a
SE ±	0.28	0.28	0.25
Varieties (V)			
Ex-Brazil 1	8.11a	3.89a	2.71a
Ex-Brazil 2	7.73a	3.72a	2.43b
Ex-India 1	7.96a	3.85a	2.54ab
Ex- India 2	6.49b	3.14b	2.06c
SE ±	0.28	0.28	0.25
Interaction			
N X P	NS	NS	*
N X V	NS	NS	*
P X V	NS	NS	NS
N X P X V	NS	NS	NS

Means within any column of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT

WAS = Weeks after sowing

NS = Not significant

* = Significant at $P \leq 0.05$

Table 4.30: Effects of interaction between N and P and varieties and N on crop growth rate of four castor varieties at 16 WAS, 2006 wet season at Samaru

	Crop growth rate (g/plant/week) N rates (kg ha^{-1})		
	0	**60**	**120**
P rates (kg ha^{-1})			
0	1.41d	1.52d	2.59c
7.92	1.47d	2.47c	3.45b
15.84	1.46d	2.80c	4.75a
SE±		0.27	
Varieties			
Ex-Brazil 1	2.08ef	2.49bc	3.55a
Ex-Brazil 2	1.27ef	2.20cd	3.82a
Ex-India 1	1.35cf	2.45bc	3.82a
Ex-India 2	1.08f	1.91def	3.19ab
SE ±		0.31	

Means within a column or row of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT.

2 had the least CGR at the same N rate. With each variety, the highest N rate produced the highest CGR.

Results of effect of N, P and variety on CGR of four castor varieties in 2007 as contained in Table 4.31 showed that significant increases in CGR were observed with each increase in N and P levels. Similarly, the same effect was recorded with P in which each increase caused significant increase in CGR.

The varietal effect on CGR in 2007 showed no significant difference produced on CGR amongst Ex- Brazil 1 and 2 and also Ex- India I at all cropping stage. Ex- India 2 produced the least CGR compared to all other varieties. The interaction between N and P and also N and Variety were significant at 16 WAS

The interaction between N and P on CGR of 2007 rainy season (Table 4.31) revealed that at 0 kg P ha $^{-1}$, only N rate of 120 kg ha $^{-1}$ produced a significant increase in CGR over the control. At other higher P rates, each increase in N from 0- 120 kg N ha^{-1} caused a significant increase in CGR. At constant 0 kg N ha^{-1}, only P rate of 15.84 kg ha^{-1} resulted in a significant increase in CGR over the control. At 60 and 120 kg N ha^{-1}, however, each increase in P rates caused a significant increase in CGR with the highest N and P rates producing the highest CGR values and vice versa.

The interaction between N and variety on CGR of castor in 2007 (Table 4.31) indicated that with each increase in N rate, the CGR produced by all the varieties also increased. At 0 kg N ha $^{-1}$, CGR produced by the two Brazilian varieties were statistically similar but higher than that of Ex-India 1. Ex-India 2 produced plant with the lowest CGR at the same N rates. This trend was observed to be produced by the same varieties at

Table 4.31: Effects of N and P rates on crop growth rate (CGR) of four castor varieties at Samaru, 2007 wet season

Treatments	Crop growth rate (g/plant/wk) 8 WAS	12 WAS	16 WAS
Nitrogen (N) ($kgha^{-1}$)			
0	6.46c	3.45c	2.08c
60	8.19b	3.94b	2.57b
120	11.54a	5.37a	3.72a
SE ±	0.22	0.37	0.18
Phosphorus (P) ($kgha^{-1}$)			
0	7.40c	3.59c	2.36c
7.92	8.49b	4.04b	2.67b
15.84	10.30a	5.14a	3.34a
SE ±	0.22	0.37	0.18
Varieties (V)			
Ex-Brazil 1	9.26a	4.57a	2.89a
Ex-Brazil 2	9.00a	4.40a	2.82a
Ex-India 1	9.13a	4.41a	2.98a
Ex- India 2	7.53b	3.65b	2.47b
SE ±	0.22	0.37	0.18
Interaction			
N X P	NS	NS	*
N X V	NS	NS	*
P X V	NS	NS	NS
N X P X V	NS	NS	NS

Means within any column of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DNMRT

WAS = Weeks after sowing

NS = Not significant

* = Significant at $P \leq 0.05$

60 kg N ha^{-1}. However, at 120 kg ha^{-1}, Ex-India 1 had the highest CGR followed by the other three varieties whose CGR values were comparable.

Result of effects of N, P and variety on CGR of castor in 2008 (Table 4.32) showed that with each increase in N and P rates, CGR values increased correspondingly. Effects of variety on CGR showed no significant difference between CGR of Ex- Brazil 1,2 and Ex-India I at all cropping stages. Ex-India 2 produced the lowest CGR all through the sampling periods. Interaction between N and P and also between N and variety were significant at 16 WAS.

Result of interaction between N and P on CGR of castor at 16 WAS (Table 4.33) revealed that at each level of P, increases in N rates significantly increase CGR in 2008. At 0 kg N ha^{-1}, only 15.84 kg P ha^{-1} significantly increased CGR over the control although it was comparable to CGR at 7.92 kg P ha^{-1}. However, at 60 and 120 kg N ha^{-1} each increase in N rate resulted in significant increased in CGR values. The highest CGR was produced by 120 kg N ha^{-1} and 15.84 kg P ha^{-1} while the lowest was produced by untreated control.

The interaction between N and variety on CGR of castor at 16 WAS in 2008 (Table 4.34) revealed that with each increase in N rates there was a significant increase in CGR regardless of variety. At 0 N level, Ex-Brazil 1 produced the highest CGR followed by Ex-Brazil 2 and Ex-India 1 that had statistically similar CGR. At 60 kg N ha^{-1}, the three castor varieties had statistically similar CGR that was higher than that of Ex-India 2. At 120 kg N ha^{-1}, Ex-India 2 produced the least CGR but was similar to Ex-Brazil 1. The other varieties had comparable CGR values.

Table 4.32: Effect of interaction between N and P and varieties and N on crop growth rate of four castor varieties at 16 WAS, 2007 wet season at Samaru

	Crop growth rate (g/plant/week) N rates (kg ha^{-1})		
	0	**60**	**120**
P rates (kg ha^{-1})			
0	2.03g	2.02g	3.01d
7.92	1.96g	2.46e	3.59b
15.84	2.23f	3.25c	4.55a
SE±		0.05	
Varieties			
Ex-Brazil 1	2.31e	2.71cd	3.63b
Ex-Brazil 2	2.22ef	2.68d	3.57b
Ex-India 1	2.09f	2.85c	4.01a
Ex-India 2	1.68g	2.05f	3.66b
SE ±		0.06	

Means within a column or row of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT.

Table 4.33: Effects of N and P rates on crop growth rate (CGR) of four castor varieties at Samaru, 2008 wet season

Treatments	Crop growth rate (g/plant/wk) 8 WAS	12 WAS	16 WAS
Nitrogen (N) ($kgha^{-1}$)			
0	7.08c	3.44c	2.26c
60	8.86b	4.35b	2.75b
120	13.00a	6.29a	4.01a
SE ±	0.37	0.38	0.22
Phosphorus (P) ($kgha^{-1}$)			
0	7.89c	3.92c	2.49c
7.92	9.67b	4.74b	2.99b
15.84	11.38a	5.42a	3.53a
SE ±	0.37	0.38	0.22
Varieties (V)			
Ex-Brazil 1	9.94a	4.71ab	3.06a
Ex-Brazil 2	9.86a	4.88a	3.06a
Ex-India 1	10.08a	4.85a	3.17a
Ex- India 2	8.71b	4.34b	2.74b
SE ±	0.37	0.38	0.22
Interaction			
N X P	NS	NS	*
N X V	NS	NS	*
P X V	NS	NS	NS
N X P X V	NS	NS	NS

Means within any column of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT

WAS = Weeks after sowing

NS = Not significant

* = Significant at $P \leq 0.05$

Table 4.34: Effects of interaction between N and P and varieties and N on crop growth rate of four castor varieties at 16 WAS, 2008 wet season at Samaru

	Crop growth rate (g/plant/week) N rates (kg ha^{-1})		
	0	**60**	**120**
P rates (kg ha^{-1})			
0	2.22h	2.34g	3.9c
7.92	2.24gh	2.64e	4.11b
15.84	2.32fg	3.27d	5.00a
SE ±		**0.07**	
Varieties			
Ex-Brazil 1	2.53f	2.75e	3.89bc
Ex-Brazil 2	2.23g	2.83de	4.1ab
Ex-India 1	2.77g	3.01d	4.21a
Ex-India 2	1.99h	2.40fg	3.82c
SE ±		0.08	

Means within a column or row of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT.

4.1.7 Leaf area index (LAI)

The effect of N, P and variety on LAI of castor in 2006 rainy season (Table 4.35) showed a significant increase in LAI when N level was raised from 0 to 120 kg N ha^{-1} at all sampling periods. Application of 60 kg N/ha did not increase LAI of castor. There was no significant difference in LAI with each increase in P rates at 4 and 12 WAS in 2006. However, LAI of castor significantly increased when P rates were raised above 7.92 kg P ha^{-1} at 8 and 16 WAS.

Varietal effect of LAI on four castor varieties indicated no significant difference in all the four varieties of castor at 8, 12 and 16 WAS. However at 4 WAS, Ex-India 1 produced the lowest LAI compared to the other three varieties. There was no significant interaction among the various factors in 2006.

Result of effect of N, P and variety on LAI of castor in 2007 wet season (Table 4.36) revealed a significant increase in LAI when N level was raised up to 60 kg N ha^{-1} at 4, 8, and 12 WAS. At 16 WAS there was no significant change in LAI when N levels were varied. Similarly, varying P levels in 2007 did not produced any significant change in LAI of castor at 4, 8, and 16 WAS. However, at 12 WAS, LAI of castor increased significantly when P was raised to 7.92 kg P ha^{-1}. Varietal effect on LAI of castor in 2007 did not show any significant difference. Also interaction effect among the various factors tested did at show any significant difference in the year under review.

Result from Table (4.37) indicated that at 8, 12 and 16 WAS in 2008, LAI of castor significantly increased when N level was raised from 0 to 60 kg N ha^{-1}. However, at 4 WAS, it was observed that LAI of castor increased with each increase in N rates. It was observed that plots supplied with P rate up to 7.92 kg P ha^{-1} at 4 WAS produced a

Table 4.35: Effects of N and P rates on LAI of four castor varieties, 2006 wet season at Samaru

Treatments	Leaf Area Index 4 WAS	8 WAS	12 WAS	16 WAS
Nitrogen (N) (kgha^{-1})				
0	3.21b	5.41b	5.53b	6.21b
60	4.72ab	7.01ab	7.91ab	8.52ab
120	5.61a	7.53a	8.17a	8.90a
SE ±	0.70	0.74	0.76	0.82
Phosphorus (P) (kgha^{-1})				
0	3.00a	3.21b	4.11	4.21b
7.92	3.69ab	5.17ab	5.23	5.81ab
15.84	4.87a	6.32a	6.53	6.73a
SE ±	0.70	0.74	0.76	0.87
Varieties (V)				
Ex-Brazil 1	7.31a	8.30a	8.73	8.91
Ex-Brazil 2	5.11ab	7.11ab	7.90	8.13
Ex-India 1	4.42b	6.43ab	7.23	7.82
Ex- India 2	7.21a	8.23ab	8.555	8.90
SE ±	0.72	0.76	0.79	0.87
Interaction				
N X P	NS	NS	NS	NS
N X V	NS	NS	NS	NS
P X V	NS	NS	NS	NS
N X P X V	NS	NS	NS	NS

Means within any column of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT

WAS = Weeks after sowing

NS = Not significant

Table 4.36: Effects of N and P rates on LAI of four castor varieties in 2007 wet season at Samaru

Treatments	Leaf Area Index 4 WAS	8 WAS	12 WAS	16 WAS
Nitrogen (N) (kgha^{-1})				
0	4.12 b	4.21b	4.95b	6.01
60	5.20a	6.70a	7.20a	7.51
120	5.91a	6.91a	7.21a	8.02
SE ±	0.70	0.73	0.75	0.80
Phosphorus (P) (kgha^{-1})				
0	3.92	4.02	4.15b	5.30
7.92	4.10	4.91	5.20a	5.91
15.84	4.72	5.42	6.31a	6.62
SE ±	0.70	0.73	0.75	0.80
Varieties (V)				
Ex-Brazil 1	6.31	8.01	8.50	8.81
Ex-Brazil 2	5.28	7.11	7.32	7.91
Ex-India 1	4.73	6.58	7.11	7.78
Ex- India 2	6.22	8.11	8.43	8.72
SE ±	0.73	0.83	0.76	0.84
Interaction				
N X P	NS	NS	NS	NS
N X V	NS	NS	NS	NS
P X V	NS	NS	NS	NS
N X P X V	NS	NS	NS	NS

Means within any column of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT

WAS = Weeks after sowing

NS = Not significant

significant increase in LAI. However, at 8 WAS there was no significant change in LAI when the P rates were varied, At 12 WAS, each increase in P rates produced a significant difference in LAI while LAI at 16 WAS was only increased when P rate was raised to 15.84 kg P ha^{-1}.

Varietal effect of LAI in 2008 indicated that at 4, 12 and 16 WAS, Ex-Brazil 1 and Ex-Brazil 2 produced the highest LAI whose results were at par while Ex-Brazil 2 and Ex-India 1 produced statistically similar but lower LAI. At 8 WAS, however, Ex-India 2 produced plants with the highest LAI followed by Ex-Brazil 1. Ex-Brazil 2 and Ex-India 1 produced statistically similar but lower LAI in the year under review. There was a significant interaction between N and P at 16 WAS in 2008.

The effect of interaction between N and P on LAI of castor in 2008 as shown on Table 4.38 revealed that at each level of applied P, only an increase in rate of N above 60 kg N ha^{1-} significantly increased LAI of castor. At constant 0 and 60 kg N ha^{-1}, only the application of P up to 7.92 kg/ha caused a significant difference in LAI of castor but further increase above this rate resulted to no change in LAI. At 120 kg N ha^{-1}, there was no significant change in LAI when the P rates were altered. The application of highest N and P rates produced the highest LAI of castor at 16 WAS in 2008.

4.1.8 Net assimilation rate (NAR)

Presented in Table 4.39 are effects of N, P and variety on NAR of castor in 2006 which showed no statistical differences in the NAR at 12 and 16 WAS when the application of N was varied, however, at 8 WAS, each increase N level resulted in a significant increase in NAR value. Each P application resulted in significant increase of NAR at 8 WAS.

Table 4.37: Effects of N and P rates on LAI of four castor varieties in 2008 wet season at Samaru

Treatments	Leaf Area Index 4 WAS	8 WAS	12 WAS	16 WAS
Nitrogen (N) (kgha^{-1})				
0	4.40c	6.40b	5.70b	8.10b
60	5.51b	7.51ab	8.10a	9.70a
120	7.21a	8.01a	8.50a	10.21a
SE ±	0.24	0.34	0.49	0.52
Phosphorus (N) (kgha^{-1})				
0	3.90b	4.41	4.41c	5.80b
7.92	4.71a	5.10	5.60b	6.20b
15.84	5.10a	5.52	7.21a	7.90a
SE ±	0.24	0.34	0.49	0.52
Varieties (V)				
Ex-Brazil 1	10.00a	10.21b	11.20a	12.23a
Ex-Brazil 2	7.10b	8.21c	8.93b	9.21b
Ex-India 1	6.90b	8.01c	8.74b	9.20b
Ex- India 2	10.10a	11.50a	12.13a	12.10a
SE ±	0.28	0.36	0.51	0.54
Interaction				
N X P	NS	NS	NS	*
N X V	NS	NS	NS	NS
P X V	NS	NS	NS	NS
N X P X V	NS	NS	NS	NS

Means within any column of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DNMRT

WAS = Weeks after sowing

NS = Not significant

* = Significant at $P \leq 0.05$

Table 4.38: Interaction between N and P rates on LAI of four castor varieties, 2008 wet season at Samaru

	Leaf Area Index		
	N rates (kg ha^{-1})		
P rates (kg ha^{-1})	**0**	**60**	**120**
0	6.42d	6.30d	8.84abc
7.92	7.17bcd	7.40bcd	9.09ab
15.84	8.21bcd	8.13bcd	11.15a
SE±		0.82	

Means within a column or row of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT.

The effect of variety indicated that irrespective of sampling period all the varieties did not produce any significant statistical variation in NAR values except at 8 WAS where Ex- India 1 produced significantly lower NAR than the other varieties. None of the interactions was significant at any period of sampling.

The effect of N, P and variety on NAR in 2007 rainy season is presented on Table 4.40. The result revealed that NAR was increased with each increase in quantity of N at each sampling period except at 12 WAS when only application of N beyond 120 kg N ha^{-1} caused a significant increase in NAR. At 8 and 16 WAS each increase in the rates of P, significantly increased NAR of castor. At 12 WAS, only the application of 15.84 kg P ha^{-1} resulted in significant increase in NAR over the control. The NAR of the four varieties at 12 and 16 WAS did not show any statistical variation, however at 8 WAS, both Brazilian varieties and Ex-India 1 produced comparable results that were statistically higher than Ex- India 2. There was no any significant interaction at all the sampling periods in year 2007.

The effect of N, P and variety on NAR in 2008 rainy season (Table 4.41) indicated that at 8 and 12 WAS there was a significant increase in NAR with each increase in N rates. However 16 WAS, only the highest N level that produced a higher NAR than the untreated control. Similarly, each increase in applied P led to a significant increase in NAR except at 16 WAS when only an increase beyond 7.92 kg P ha^{-1} increased in NAR significantly over the control.

Varietal effect in the same year revealed that at 8 WAS, the three varieties of castor produced comparable NAR that were higher than that of Ex- India 2.

Table 4.39: Effect of N and P rates on net assimilation rate (NAR) of four castor varieties, 2006 wet season at Samaru

Treatments	Net assimilation rate ($g/cm^2/day$) 8 WAS	12 WAS	16 WAS
Nitrogen (N) ($kgha^{-1}$)			
0	0.24c	0.30	2.36
60	0.47b	1.24	1.37
120	0.85a	1.13	2.10
SE ±	0.20	3.12	3.95
Phosphorus (P) ($Kgha^{-1}$)			
0	0.36c	0.32	0.97
7.92	0.54b	0.74	1.36
15.84	0.67a	1.62	3.49
SE ±	0.20	3.12	3.95
Varieties (V)			
Ex-Brazil 1	0.54a	0.47	1.83
Ex-Brazil 2	0.55a	1.78	1.42
Ex-India 1	0.56a	0.66	3.35
Ex- India 2	0.44b	0.66	1.16
SE ±	0.20	3.12	3.96
Interaction			
N X P	NS	NS	NS
N X V	NS	NS	NS
P X V	NS	NS	NS
N X P X V	NS	NS	NS

Means within a column of treatments followed by unlike letter(s) are significantly different at 5% level of probability using DMRT

WAS = Weeks after sowing

NS = Not significant

Table 4.40: Effects of N and P rates on net assimilation rate (NAR) of four castor varieties, 2007 wet season at Samaru

Treatment	Net assimilation rate ($g/cm^2/day$) 8 WAS	12 WAS	16 WAS
Nitrogen (N) ($kgha^{-1}$)			
0	0.44c	0.62b	0.84c
60	0.59b	0.53b	1.48b
120	0.85a	1.51a	3.08a
SE ±	0.07	0.86	0.22
Phosphorus (P) ($kgha^{-1}$)			
0	0.53c	0.71b	1.04c
7.92	0.61b	0.80ab	1.68b
15.84	0.75a	1.13a	2.68a
SE ±	0.07	0.87	0.22
Varieties (V)			
Ex-Brazil 1	0.66a	0.87	1.87
Ex-Brazil 2	0.65a	1.17	1.76
Ex-India 1	0.67a	0.77	1.71
Ex- India 2	0.53b	0.72	1.86
SE ±	0.07	0.87	0.22
Interaction			
N X P	NS	NS	NS
N X V	NS	NS	NS
P X V	NS	NS	NS
N X P X V	NS	NS	NS

Means within a column of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT

WAS = Weeks after sowing

NS = Not significant

At 12 WAS, Ex- Brazil 1 had the highest NAR followed by Ex- Brazil 2, the two Indian varieties produced lower but similar NAR. At 16 WAS however, the highest NAR was produced by Ex-India 2 but was similar to Ex-India 1 and Ex-Brazil 1. Neither the first order nor the second order of interaction was significant all through the experimental trial of 2008.

4.1.9 Days to 50% first flowering

Effects of N, P and variety on number of days to 50% first flowering in 2006, 2007, 2008 and the combined means are presented in Table 4.42. The result showed that in 2006, varying N levels 0 -120kg N ha^{-1} caused a significant increase in days to 50% first flowering. Similarly the same trend was observed in 2007, 2008 and the combined mean. Application of P resulted in significant increase in number of days to 50% first flowering in 2008 and combined, However, in 2006 and 2007, increase in P up to 7.92 kg ha^{-1} resulted in more number of days to 50% first flowering but further increase up to 15.84 kg P ha^{-1} caused a decrease in number of days to 50% first flowering but higher than in the control. In 2006, the two Indian varieties had more number of days to 50% first flowering compared with their Brazilian counterpart varieties with Ex- India 2 and Ex- Brazil 1 producing the highest and the lowest numbers of days to 50% first flowering respectively. In 2007 and 2008, the two Indian varieties produced the lowest but comparable number of days to 50% first flowering each significantly lower than Ex- Brazil 1. Ex- Brazil 2 had the highest number of days to 50% first flowering in both years and in the combined.

Table 4.41: Effects of N and P rates on net assimilation rate (NAR) of four castor varieties, 2008 wet season at Samaru

Treatment	Net assimilation rate ($g/cm^2/day$) 8 WAS	12 WAS	16 WAS
Nitrogen (N) ($kgha^{-1}$)			
0	0.50c	0.83c	0.85b
60	0.62b	1.92b	0.54c
120	0.95a	3.12a	1.18a
SE ±	0.13	0.24	0.29
Phosphorus (P) ($kgha^{-1}$)			
0	0.56c	1.15c	0.67b
7.92	0.68b	1.89b	0.67b
15.84	0.82a	2.83a	1.23a
SE ±	0.13	0.24	0.29
Varieties (V)			
Ex-Brazil 1	0.69a	2.21a	0.84ab
Ex-Brazil 2	0.70a	1.98b	0.77b
Ex-India 1	0.74a	1.90bc	0.88ab
Ex- India 2	0.62b	1.73c	0.93a
SE ±	0.13	0.24	0.29
Interaction			
N X P	NS	NS	NS
N X V	NS	NS	NS
P X V	NS	NS	NS
N X P X V	NS	NS	NS

Means within a column of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT

WAS = Weeks after sowing

NS = Not significant

Table 4.42: Effects of N and P rates on days to 50% first flowering of four castor varieties at Samaru, 2006, 2007, 2008 wet seasons and combined

Treatments	Days to 50% flowering 2006	2007	2008	Combined
Nitrogen (N) (kgha^{-1})				
0	1.00c	29.42c	29.03c	19.81c
60	47.06b	64.94b	63.28b	58.43b
120	69.78a	66.72a	65.31a	67.27a
SE ±	0.25	0.38	0.34	0.33
Phosphorus (P) (kgha^{-1})				
0	27.33c	41.69c	40.67c	36.56c
7.92	46.13a	61.31a	56.72b	53.06b
15.84	44.36b	58.03b	60.22a	55.89a
SE ±	0.25	0.38	0.34	0.33
Varieties (V)				
Ex-Brazil 1	35.30d	63.37b	61.96b	53.54b
Ex-Brazil 2	37.78c	67.74a	66.78a	57.43a
Ex-India 1	40.93b	41.70c	40.56c	41.06d
Ex- India 2	43.11a	41.96c	40.85c	41.98c
SE ±	0.25	0.38	0.34	0.33
Interaction				
N X P	NS	NS	NS	*
N X V	NS	NS	NS	*
P X V	NS	NS	NS	*
N X P X V	NS	NS	NS	NS

Means within a column of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT

NS = Not significant

* = Significant at $P \leq 0.05$

In the combined, the Brazilian varieties had more number of days to 50% first flowering than the two Indian varieties with Ex- Brazil 2 and Ex- India 2 producing the highest and the lowest number of days to 50% first flowering respectively. First order of interaction between N and P, N and variety and also P and variety were significant when the mean of the three years result was combined.

The interaction between N and P rates on days to 50% first flowering on combined mean is presented on Table 4.43. The result showed that holding 0 kg P ha^{-1} constant, each increase in N rates from 0- 120 kg N ha^{-1} caused a significant increase in number of days to 50% first flowering, At 7.92 and 15.84 kg P ha^{-1}, only increase up to 60 kg N ha^{-1} caused a significant increase beyond which number of days to 50% first flowering was reduced but still significantly higher at 0 kg N ha^{-1}. At constant 0 and 60 kg N ha^{-1}, increase in P up to 7.92 kg ha $^{-1}$ resulted in a significant increases. Further application of higher P rate caused no change at 0 kg N ha^{-1} but decrease days to 50% first flowering at 60 kg N ha^{-1}. However, at the highest level of N, each increase in the rate of P caused a significant decrease in days to 50% flowering. The highest N rate without any P produced the highest number of days to 50% first flowering while the least number of days to 50% first flowering was produced in the plots that received neither N nor P.

The interaction effect between N rates and variety on days to 50% flowering of the combined analysis result (Table 4.43) showed that with the two Brazilian varieties, application of 60 kg ha $^{-1}$ significantly increased number of days to 50% first flowering relative to control. Application of higher N level only caused a significant decline in number of days to 50% first flowering but higher than the untreated control. With the two

Indian varieties however, each increase in N rates resulted to a significant increase in number of days to 50% first flowering. The highest number of days to 50% first flowering was produced at the highest level of N by the Indian varieties while the least was produced in the control by Ex-Brazilian 1 variety.

Result of interaction of P and variety (Table 4.44) on days to 50% first flowering of castor in the combined analysis indicates that Ex- Brazil I and 2 had their number of days to 50% first flowering significantly increasing with a rise in P rate up to 7.92 kg ha $^{-1}$ beyond which a depressed result was noted. With the two Indian varieties, maximum number of days were recorded with 7.92 kg P ha $^{-1}$ beyond which application of P had no further influence on the result. At each level of P, Ex- Brazil 2 produced the highest number of days to 50% first flowering followed by Ex- Brazil 1. Ex- India 1 and 2 had lower but comparable results except with 7.92 kg P ha^{-1} when Ex- India 2 had statistically higher number of days to 50% first flowering. The highest number of days was produced by Ex- Brazil 2 with 7.92 kg P ha^{-1} while lowest was produced by the Indian varieties in the control experiment.

4.2 Yield and Yield Components

4.2.1 Capsule weight per plant

The effect of N, P and variety on capsule weight per plant in 2006, 2007, 2008 and the combined mean at Samaru presented in Table 4.45 showed that in all the three years and the combined, each increase in N, significantly increased the weight of capsules on each plant. The effect of P showed that in 2007, 2008 and the combined, each increase in rate of P resulted in significant increase in capsule weight per plant.

Table 4.43: Effect of interaction between N and P and varieties and N rates on days to 50% flowering of four castor varieties,2006, 2007 and 2008 wet seasons at Samaru

	Days to 50% flowering N rates (kg ha^{-1})		
	0	**60**	**120**
P rates (kg ha^{-1})			
0	11.00h	28.06g	80.64a
7.92	30.28g	75.17b	62.22d
15.84	28.17g	72.06c	58.94e
SE±		0.39	
Varieties			
Ex-Brazil 1	38.11h	62.78d	59.74e
Ex-Brazil 2	39.15h	67.63b	65.52c
Ex-India 1	11.00i	50.86g	71.33a
Ex-India 2	11.00i	52.44f	72.48a
SE ±		0.45	

Means within a column or row of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT.

Table 4.44: Effect of interaction between P rates and Varieties on days to 50% first flowering of four castor varieties, 2006, 2007 and 2008 wet seasons at Samaru

	Days to 50% first flowering P rates (kg ha^{-1})		
Varieties	**0**	**7.92**	**15.84**
Ex-Brazil 1	41.89g	61.96b	56.78d
Ex-Brazil 2	47.15f	65.22a	59.93c
Ex-India 1	28.35h	47.33f	47.48f
Ex-India 2	88.85h	49.04e	48.04ef
SE ±		0.45	

Means within a column or row of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT.

However, in 2006, further increase beyond 7.92 kg k P ha^{-1} did not produce any marked effect.

The varietal responses indicated that Ex- Brazil 1 plants produced the heaviest capsules in all the three years but was comparable to Ex- India 2 in 2006. This was followed by Ex-Brazil 2 and Ex-India 1 in 2006, Ex-India 2 in 2007 and the combined and Ex-Brazil 2 in 2008. The lightest capsules were produced by Ex-India 1 in 2007 and combined, and Ex-India 2 in 2008.

All the first order interactions between N and P, N and variety and also P and variety were significant when result of the three years were combined.

The interaction between N and P rates on capsule weight per plant (Table 4.46) in the combined analysis pointed out that at 0 kg P ha^{-1}, applying 60 kg N ha^{-1} caused a significant increase in capsule weight per plant, however, no significant increase was recorded when N level was raised beyond this rate. At higher P levels, each increase in N caused a significant increase in weight of capsules produced per plant At 60 and 120 kg N ha^{-1}, each increase in the level of P caused significantly heavier capsules to be produced, however, at 0 kg N ha^{-1},

application of 7.92 kg P ha^{-1} significantly increased capsule weight per plant over the control while a further increase in P rates did not significantly alter the capsule weight per plant. The combination of the highest N and P levels produced the heaviest capsules and vice versa.

Result of interaction between N and variety in Table 4.46 revealed that irrespective of variety, there was a significant increase in capsule weight per plant as the rate of applied N was increased except with Ex- India 1 when a further increase in N above

Table 4.45: Effects of N and P rates on capsule weight per plant of four castor varieties at Samaru, 2006, 2007 and 2008 wet seasons and combined

Treatment	Capsule weight per plant (gm) 2006	2007	2008	Combined
Nitrogen (N) ($kgha^{-1}$)				
0	11.00c	15.11c	18.89c	11.67c
60	60.92b	69.81b	74.25b	68.32b
120	93.67a	121.64a	117.31a	110.87a
SE ±	4.13	1.21	0.77	2.32
Phosphorus (P) ($kgha^{-1}$)				
0	13.39b	24.97c	25.72c	3.37c
7.92	64.69a	78.92b	82.03b	4.20b
15.84	77.50a	102.67a	102.69a	5.03a
SE ±	4.13	1.21	0.77	2.32
Varieties (V)				
Ex-Brazil 1	82.70a	143.22a	152.59a	126.17a
Ex-Brazil 2	22.56b	36.48c	65.82b	33.36c
Ex-India 1	34.15b	18.70d	41.04c	24.67d
Ex- India 2	68.04a	77.00b	21.15d	70.28b
SE ±	4.13	1.21	0.77	2.32
Interaction				
N X P	NS	NS	NS	*
N X V	NS	NS	NS	*
P X V	NS	NS	NS	*
N X P X V	NS	NS	NS	NS

Means within a column of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT

NS = Not significant

* = Significant

60kg ha^{-1} did not produced any change in capsule weight. Ex- Brazil 1 produced plant with the heaviest capsule followed by Ex- India 2, both at 120 kg N ha^{-1}

From Table 4.47, result of interaction between P and variety on capsule weight per plant in the combined analysis indicated that with Ex- Brazil 1 and 2 and also Ex-India 1 only increase in P up to 7.92 kg ha^{-1} significantly increased in weight of capsule per plant. Beyond this, statistically comparable increase were recorded. With Ex- India 2, each increase in P significantly increased the weights of capsules produced by each plant.

At all levels of P, Ex- Brazil 1 produced the heaviest capsule per plant. However, at 0 kg P ha^{-1}, Ex- Brazil 2 and Ex- India 2 had comparable results that were statistically higher than Ex- India 1. At 7.92 and 15.84 kg P ha^{-1}, Ex- Brazil 2 Ex-India 1 produced capsule weight which were statistically at par but significantly lower than that produced by Ex- India 2 at both the P rates. The heaviest capsule were produced by Ex- Brazil 1 with 15.84 kg P ha^{-1} while the lightest was produced by Ex-India 1 in the control experiment.

4.2.2 Diameter of capsule

Effects of N, P and variety on diameter of capsule in the years of this research study and the combined analysis are presented are Table 4.48. The result disclosed a consistent increase in diameter of capsule with each increase in N rate in the three years and combined mean. Similarly, in 2006 and 2008, capsule diameter increased with each increase in P rate, however, in 2007 and the combined analysis, a further increases beyond 7.92 kg P ha^{-1} did not give a significant increase in capsule diameter.

Table 4.46: Interaction of N and P and varieties and N rates on capsule weight per plant of four castor varieties, 2006, 2007 and 2008 wet seasons (combined) at Samaru

	Capsule weight per plant (gm) N rates (kg ha^{-1})		
	0	**60**	**120**
P rates (kg ha^{-1})			
0	1.00g	30.19e	32.89e
7.92	18.31f	81.64d	125.69b
15.84	15.69f	93.14c	174.03a
SE±		3.09	
Varieties			
Ex-Brazil 1	34.37e	106.19b	237.96a
Ex-Brazil 2	10.30g	33.85f	55.93d
Ex-India 1	1.00i	38.19e	34.81e
Ex-India 2	1.00i	95.07c	114.78b
SE ±		3.56	

Means within a column or row of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT.

Table 4.47: Interaction between P rates and Varieties on capsule weight per plant of four castor varieties, 2006, 2007 and 2008 wet seasons (combined) at Samaru

	Capsule weight per plant (gm) P rates (kg ha^{-1})		
Varieties	**0**	**7.92**	**15.84**
Ex-Brazil 1	57.70e	137.74a	183.07a
Ex-Brazil 2	16.37h	38.07fg	45.63f
Ex-India 1	1.00i	31.89g	41.11fg
Ex-India 2	10.37h	93.15d	107.33c
SE ±		3.56	

Means within a column or row of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT.

Table 4.48: Effects of N and P rates on diameter of capsule of four castor varieties at Samaru, 2006, 2007 and 2008 wet seasons and combined

Treatments	Diameter of capsule (cm) 2006	2007	2008	Combined
Nitrogen (N) ($kgha^{-1}$)				
0	1.00c	2.44c	2.40c	1.95c
60	3.34b	5.12b	5.57b	4.68b
120	5.92a	7.95a	7.39a	7.09a
SE ±	0.09	1.93	0.13	1.19
Phosphorus (P) ($kgha^{-1}$)				
0	2.35c	3.20b	3.31c	2.96b
7.92	3.54b	6.62a	5.83b	5.33a
15.84	4.36a	5.68a	6.23a	5.43a
SE ±	0.09	1.93	0.13	1.19
Varieties (V)				
Ex-Brazil 1	3.33b	6.83a	7.20a	5.79a
Ex-Brazil 2	4.03a	5.83a	4.59c	4.82b
Ex-India 1	3.16c	2.98b	3.36d	3.16c
Ex- India 2	3.16c	5.03ab	5.35b	4.51b
SE ±	0.09	1.93	0.13	1.19
Interaction				
N X P	NS	NS	NS	*
N X V	NS	NS	NS	*
P X V	NS	NS	NS	*
N X P X V	NS	NS	NS	NS

Means within a column of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT

NS = Not significant

* = Significant at $P \leq 0.05$

Varietal responses indicated that except in 2006, Ex- Brazil 1 statistically produced the highest diameter of capsule that was comparable only to Ex- Brazil 2 and Ex- India 2 in 2007. Ex- Brazil 2 was the variety that produced a highest capsule diameter in 2006 followed by Ex-Brazil 1. The lowest capsule diameter was produced by Ex- India 1 in 2008 and in the mean of the years. Interaction between N and P, N and variety and also P and variety were significant when the combined result was analyzed.

Result of interaction between N and P rates on diameter of capsule (Table 4.49) showed that a significant increase in capsule diameter with each increase in N rates under each rate of P. In plots not treated with N and those that received 120kg N ha^{-1} capsule diameter significantly increase with application of 7.92 kg P ha^{-1}, but a further increase did not produced any significant increase in capsule size. At 60 kg N ha^{-1} however, each increase In P level significantly increased the diameter of capsules. The highest capsule diameter was observed with the highest combination of N and P while the lowest was noted in the plants that received neither N nor P.

In interaction between N and variety (Table 4.49) each increase in quantity of N produced a significant increase in diameter of capsules of each castor variety except Ex-India 1 where only application 120 kg N ha^{-1} increase capsule diameter over the control. At constant N levels, 0 kg N ha^{-1} had the two Brazilian varieties producing comparable results whose value was statistically higher than that of their counterpart varieties that also had statistically similar capsule diameter. At 60 kg N ha^{-1}, the three castor varieties produced statistically lower but comparable capsule diameter relative to Ex- Brazil 1.

At 120 kg N ha^{-1}, three castor varieties had significantly higher but comparable capsule diameter than Ex-India 1. The highest N rates produced the largest capsule in Ex-Brazil 1 and 2 while smaller capsule were produced by the India varieties in the control experiment.

The effect of interaction between P and variety in Table 4.50 indicated that apart from result recorded for Ex- Brazil 1, diameter of capsule of the other three castor varieties significantly increased with application of 7.92 kg P ha^{-1} over the control and Ex-Brazil 1 and the Indian varieties did not record a significant increase when P rate was further increased. With Ex-Brazil 2, the capsule diameter markedly fell with the application of higher rate of P. At each rate of N, varieties from same source had similar capsule diameter except at 120 kg N ha^{-1} when the Ex-Brazil 1 gave higher diameter than Ex-Brazil 2.. At 0 kg P ha^{-1} relative to Ex-Brazil 1, the India castor varieties produced lower but gave comparable diameter of capsules. At 7.92 kg P ha^{-1}, Ex- India 1 produced significantly lower diameter of capsule compared with result of the Brazilian. varieties. At the highest level of P, Ex- Indian 2 variety produced plants that had comparable diameter of capsules to the other three varieties.

4.2.3 Height to first raceme

When the data on effect of N, P and variety on height of first raceme was analyzed (Table 4.51), it was observed that for every increase in N rates, there was a corresponding increase in height to first raceme of castor in all the years under study and the combined analysis. The same effect was recorded for P in which each increase in P rate across the same period recorded increased height to first raceme.

Table 4.49: Interaction of N and P and varieties and N rates on diameter of capsule of four castor varieties, 2006, 2007 and 2008 wet season (combined) at Samaru

	Diameter of capsule (cm) N rates (kg ha^{-1})		
	0	**60**	**120**
P rates (kg ha^{-1})			
0	1.00g	2.55e	5.32d
7.92	2.43f	5.46c	8.09a
15.84	2.41f	6.01b	7.85a
SE ±		**0.43**	
Varieties			
Ex-Brazil 1	3.43de	6.03b	7.89a
Ex-Brazil 2	2.36e	4.53d	7.54a
Ex-India 1	1.00f	3.33df	5.16c
Ex-India 2	1.00f	4.79d	7.75a
SE ±		0.49	

Means within a column or row of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT.

Table 4.50: Interaction of P rates and Varieties on diameter of capsule of four castor varieties in 2006, 2007 and 2008 wet seasons (combined) at Samaru

	Diameter of capsule (cm) P rates (kg ha^{-1})		
Varieties	**0**	**7.92**	**15.84**
Ex-Brazil 1	4.20cde	6.09abc	7.06a
Ex-Brazil 2	2.92ef	6.50ab	5.02cd
Ex-India 1	2.00f	3.60de	3.89cdef
Ex-India 2	2.69f	5.12bcd	5.73abc
SE ±		0.49	

Means within a column or row of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT.

Result of varietal response pointed out that Ex-Brazil 1 had significantly taller height to first raceme than other varieties except with Ex- India 2 that is also a big seeded variety in 2006 with which it did not significantly differ. Ex- Brazil 2 was next but with statistically similar result with Ex- India 2 at the combined analysis. The shortest height to first raceme was produced by Ex- India 1 and Ex-India 2 in 2007 and 2008, respectively. All the first order of interaction between N and P, N and variety and also P and variety were significant when the three years result was combined.

The interaction of N and P on height to first raceme in the combined analysis (Table 4.52) showed that at each level of P, significant increases were observed with each increase in the quantity of N. There was a similar increase in height to first raceme with each increase in rate of P at constant 60 and 120 kg N ha^{-1}. However, at constant 0 kg N ha^{-1}, change in level of applied P from 7.92 to 15.84 kg ha^{-1} had no significant effect on height to first raceme. The combination of the highest rates of N and P gave the tallest heights to first raceme while the untreated control gave the shortest.

Results in Table 4.52 showed the interaction of N and variety on height to first raceme of castor in the combined analysis. The results indicated that irrespective of variety, each increase in N rates resulted to significant increase in height to first raceme. At each fertilizer rate, Ex- Brazil 1 were taller than the other varieties except when at 120 kg N ha^{-1} where another big seeded variety, Ex- India 2 and Ex- Brazil 1 produced statistically similar plant height to first raceme. At constant 0 kg N ha^{-1}, Ex-Brazil 2 had taller plant height to first capsule relative to the two Indian varieties whose values were statistically comparable.

Table 4.51: Effects of N and P rates on height to first raceme of four castor varieties at Samaru, 2006, 2007, 2008 wet seasons and combined

Treatments	Height to first raceme (cm) 2006	2007	2008	Combined
Nitrogen (N) ($kgha^{-1}$)				
0	11.00c	17.06c	17.72c	11.93c
60	39.72b	51.22b	52.89b	47.94b
120	67.17a	72.72a	76.72a	72.20a
SE ±	0.56	0.61	0.53	0.57
Phosphorus (P) ($kgha^{-1}$)				
0	17.19c	28.36c	29.36c	24.97c
7.92	43.14b	52.56b	54.78b	50.16b
15.84	47.56a	60.08a	63.19a	56.94a
SE ±	0.56	0.61	0.53	0.57
Varieties (V)				
Ex-Brazil 1	41.78a	62.82a	65.52a	56.70a
Ex-Brazil 2	31.07b	49.59b	52.15b	44.27b
Ex-India 1	27.85c	32.22d	44.89c	31.32c
Ex- India 2	43.15a	43.37c	33.89d	43.80b
SE ±	0.56	0.61	0.53	0.57
Interaction				
N X P	NS	NS	NS	*
N X V	NS	NS	NS	*
P X V	NS	NS	NS	*
N X P X V	NS	NS	NS	NS

Means within a column of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DNMRT

NS = Not significant

* = Significant at $P \leq 0.05$

At 60 kg N ha-1 level, Ex- Brazil 2 produced taller heights than Ex- India 2. The shortest height to first raceme was produced by Ex- India 1. At 120 kg N ha^{-1}, Ex-Brazil 2 had taller heights to first raceme relative to Ex-India 1. The tallest height were produced by Ex-Brazil 1 with the application of 120 kg N ha^{-1} while the shortest was by Ex-India 2 in the untreated control.

The result of the interaction of P and variety on height to first capsule of castor in the combined analysis (Table 4.53) indicates a consistent increase in height to first capsule for each variety with each increase in P rates. At each level of P, Ex- Brazil 1 produced plant with significantly taller plant heights to first capsule, this was followed by Ex- Brazil 2. The shortest heights to first raceme came from Ex-India 2 at 0 kg P ha^{-1} while Ex-Brazil 2 and Ex-India 2 produced comparable heights to first raceme with each of 7.92 and 15.84 kg Pha^{-1}.

4.2.4 100 - Seed weight

Effect s of N, P and variety on 100 - seed weight in 2006, 2007, 2008 and the combined analysis (Table 4.54) indicated that varying N levels caused significant differences in 100 – seed weights.

Increase in rate of N significantly increased 100 – seed weight in each year and in the mean of the years. A similar trend was observed with each increase in P except in 2007 when a further increase beyond 7.92 kg P ha^{-1} caused no significant positive change. Variety Ex- Brazil 1 produced the heaviest 100 - seed weight through out the experimental period and in the mean of the years followed by Ex- India 2.

Table 4.52: Interaction between N and P rates and varieties and N on height to first raceme of four castor varieties, 2006, 2007 and 2008 wet seasons (combined) at Samaru

	Height to first raceme (cm) N rates (kg ha^{-1})		
P rates (kg ha^{-1})	**0**	**60**	**120**
0	1.00h	19.17f	54.75e
7.92	17.50g	60.89d	72.08b
15.84	12.20g	63.78c	89.78a
SE+		0.63	
Varieties			
Ex-Brazil 1	24.93h	59.78c	85.41a
Ex-Brazil 2	20.78i	49.85e	62.19b
Ex-India 1	1.00j	36.37g	56.59d
Ex-India 2	1.00j	45.78f	84.63a
SE ±		0.72	

Means within a column or row of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT.

Table 4.53: Effects of P rates and varieties interaction on height to first raceme of four castor varieties, 2006, 2007 and 2008 wet seasons (combined) at Samaru

	Height to first raceme (cm) P rates (kg ha^{-1})		
Varieties	**0**	**7.92**	**15.84**
Ex-Brazil 1	33.81g	62.07b	74.22a
Ex-Brazil 2	29.30h	50.41d	53.11c
Ex-India 1	15.37i	36.44f	42.15e
Ex-India 2	21.41j	51.70d	58.30c
SE ±		0.72	

Means within a column of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT.

The lightest 100 - seeds in 2007, 2008 and the combined analysis was produced by Ex-India 1 whose result in 2006 was comparable with Ex- India 2. Interaction between N and P, N and variety and P and variety in the combined analysis were all significant.

The effects of interaction of N and P on four varieties of castor in the combined analysis (Table 4.55) revealed that with each increase in amount of N at each P level there was an increase in the weight of 100 - seeds except at 7.92 kg P ha^{-1} where applying N beyond 60 kg ha^{-1} had no effect on 100 - seed weight relative to the control. At 0 and 60 kg N ha^{-1} there was no significant response in 100 - seed weight of castor when P rate was raised from 7.92 to 15.84 kg P ha^{-1}, however, at 120 kg N ha^{-1}, each increase in P level caused a significant increase in weight of 100 - seeds.

Interaction effect between N and variety on 100 - seed weight of castor in the combined analysis as presented in Table 4.55 showed that the weight of 100 - seeds of the four castor varieties tend to increase as each rates of N was raised from 0 – 120 kg N ha^{-1}. The two Indian varieties at 0 kg N ha^{-1} produced the lowest but statistically similar 100 seed weight while Ex- Brazil 1 produced the highest. At 60 kg N ha^{-1}, Ex-Brazil 1 and Ex-India 2 produced the heaviest but comparable 100 – seed weight. At 120 kg N ha^{-1} Ex-Brazil 2 and Ex-India 1 produced the lightest but comparable 100 seed weights. At 120 kg N ha^{-1}, the big seeded varieties gave a lead in producing the heaviest but comparable 100 - seed weights where Ex- Brazil 1 produced the heaviest followed by Ex-India 2. Ex-Brazil 2 had similar 100 - seeds with Ex-India 1 at the same N rates. The highest rate of N produced the heaviest 100 - seeds while lower N rates produced lighter 100 – seed as eights.

Table 4.54: Effects of N and P rates on 100 seed weight of four castor varieties at Samaru, 2006, 2007 and 2008 wet seasons

Treatments	100 seed weight (g) 2006	2007	2008	Combined
Nitrogen (N) (kgha^{-1})				
0	1.00c	9.12c	9.38c	6.50c
60	18.24b	24.48b	25.66b	22.79b
120	24.48a	27.18a	26.66a	26.11a
SE ±	1.21	0.90	0.40	0.86
Phosphorus (P) (kgha^{-1})				
0	5.21c	9.86b	10.08c	8.39c
7.92	17.56b	25.71a	25.30b	22.86b
15.84	20.94a	25.21a	26.30a	24.15a
SE ±	1.21	0.90	0.40	0.86
Varieties (V)				
Ex-Brazil 1	27.86a	42.05a	43.96a	37.95a
Ex-Brazil 2	5.88c	10.36c	9.43c	8.56c
Ex-India 1	5.08c	4.99d	5.62d	5.23d
Ex- India 2	19.48b	23.65b	23.25b	22.13b
SE ±	1.21	0.90	0.40	0.86
Interaction				
N X P	NS	NS	NS	*
N X V	NS	NS	NS	*
P X V	NS	NS	NS	*
N X P X V	NS	NS	NS	NS

Means within a column of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DNMRT

NS = Not significant

* = Significant at $P \leq 0.05$

Interaction effect of P and variety on 100 - seed weight of four castor varieties in the combined analysis is shown in Table 4.56. The result indicated that with each of the big seeded varieties (Ex- Brazil 1 and Ex-India 2), each increase in P rate caused a significant increase in 100 seed weight. With Ex- Brazil 2 and Ex- India 1 (the small - seeded varieties), increase in P beyond 7.92 kg ha^{-1} did not cause any significant increase in 100 - seed weight. At all levels of P, Ex- Brazil 1 produced the heaviest 100 - seed weight. At 0 kg P ha^{-1}, the two Indian varieties produced statistically similar but lower 100 - seed weight relative to Ex- Brazil 2. At 7.92 kg P ha^{-1} and higher, Ex- India 2 produced significantly heavier 100 - seed weight over Ex- Brazil 2 with Ex-India 1 producing the lightest 100 - seed weights lowest 100 - seed weight was produced in the untreated control with the Indian varieties.

4.2.5. Number of capsules per raceme

Result of effect of N, P and variety on number of capsules per raceme analyzed for the three years and the combined (Table 4.57) pointed out that each increase in N rate resulted in significant increase in number of capsules per raceme. The same trend was recorded for each increase in P rates.

Varietal effect revealed that Ex- Brazil 2 produced the highest number of capsule per raceme in all the years of the experiment and the combined analysis. However, this result was statistically comparable with Ex- India 1 in 2007. The highest P rate produced the highest 100 - seed weight with Ex- Brazil 1 while the

Ex-Brazil 1 was observed to have produce the next higher number of capsules per raceme followed by Ex- India 1 in 2006, 2008 and the combined analysis.

Table 4.55: Interaction between N and P and varieties and N rates on 100-seed weight of four castor varieties, 2006, 2007 and 2008 wet seasons (combined) at Samaru

	100 - seed weight (gm) N rates (kg ha^{-1})		
	0	**60**	**120**
P rates (kg ha^{-1})			
0	1.00e	10.01d	14.15c
7.92	8.95d	29.64b	29.99b
15.84	9.54d	28.74b	34.18a
SE±		**0.62**	
Varieties			
Ex-Brazil 1	19.34d	42.46b	52.06a
Ex-Brazil 2	2.36e	4.53d	7.54c
Ex-India 1	2.00f	3.33e	5.16c
Ex-India 2	2.00f	40.79b	.47.75a
SE ±		0.49	

Means within a column or row of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT.

Table 4.56: Interaction of P rates and Varieties on 100-seed weight of four castor varieties, 2006, 2007 and 2008 wet seasons (combined) at Samaru

	100-seed weight (gm) P rates (kg ha^{-1})		
Varieties	**0**	**7.92**	**15.84**
Ex-Brazil 1	25.72e	42.74b	45.40a
Ex-Brazil 2	5.82h	10.59f	9.26fg
Ex-India 1	1.00i	7.23gh	7.46gh
Ex-India 2	1.00i	30.88d	34.50c
SE ±		0.71	

Means within a column or row of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT.

Table 4.57: Effects of N and P rates on number of capsules per raceme of four castor varieties at Samaru, 2006, 2007, 2008 wet seasons and combined

Treatments	Number of capsules per raceme 2006	2007	2008	Combined
Nitrogen (N) (kgha^{-1})				
0	11.00c	19.00c	24.00c	14.67c
60	41.44b	59.06b	71.83b	57.44b
120	93.50a	111.83a	136.83a	114.06a
SE ±	1.60	1.85	1.4	1.62
Phosphorus (P) (Kgha^{-1})				
0	10.83c	22.89c	36.22c	23.32c
7.92	48.11b	69.06b	84.61b	67.26b
15.84	77.00a	97.94a	111.83a	95.59a
SE ±	1.60	1.85	1.41	1.62
Varieties (V)				
Ex-Brazil 1	53.04b	83.07b	100.11b	78.74b
Ex-Brazil 2	67.11a	98.63a	121.59a	95.78a
Ex-India 1	35.37c	40.56a	49.44c	41.79c
Ex- India 2	25.74d	30.93d	39.07d	31.91d
SE ±	1.60	1.85	1.41	1.62
Interaction				
N X P	NS	NS	NS	*
N X V	NS	NS	NS	*
P X V	NS	NS	NS	*
N X P X V	NS	NS	NS	NS

Means within a column of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT

NS = Not significant

* = Significant $P \leq 0.05$

The least number of capsules per raceme were produced by Ex- India 2 in all the three years of this research and the combined analysis. Significant interaction existed between N and P, N and variety and also P and variety when the result of the three years were combined and analysed.

Result of interaction between N and P on number of capsules per raceme of four castor varieties in the combined analysis (Table 4.58) revealed that significant increases resulted when N rates were raised from 0-120 kg N ha^{-1}.Varying P levels, at 0 kg N ha^{-1}, increase in P rates beyond 7.92 kg P ha^{-1} did not produce significant increase, however, at higher rates of N, each increase in P rates resulted in significant increase in number of capsules per raceme.

The combination with the highest N and P produced the highest number of capsules per raceme and vice versa.

Result of interaction between N and variety (Table 4.58) on number of capsules per raceme of four castor varieties indicated a significant increase amongst all the four varieties with each increase in N rates. At each level of N, Ex- Brazil 2 produced the highest number of capsules per raceme. At 0 kg N ha^{-1}, the Indian varieties produced statistically comparable but lower number of capsule per raceme relative to Ex- Brazil 1 and 2. At 60 and 120 kg N ha^{-1}, number of capsules per raceme produced by Ex- Brazil 1 was significantly higher than Ex- India 1 that was in turn higher than Ex- India 2. The highest number of capsules was produced by Ex- Brazil 2 with the highest N rates while the lowest was produced by the Indian varieties in the untreated control.

Effect of interaction between P and variety on number of capsules per raceme of four castor varieties in the combined analysis as revealed in Table 4.59 indicated that

Table 4.58: Interaction between N and P rates and varieties and N rates on number of capsules per raceme of four castor varieties, 2006, 2007 and 2008 wet seasons (combined) at Samaru

	Number of capsules per raceme N rates (kg ha^{-1})		
P rates (kg ha^{-1})	**0**	**40**	**80**
0	1.00h	27.33f	41.61e
7.92	20.11g	62.78d	118.89b
15.84	22.89fg	82.22c	181.67a
SE+		**2.13**	
Varieties			
Ex-Brazil 1	25.74g	74.93d	135.56b
Ex-Brazil 2	30.93f	91.22e	165.19a
Ex-India 1	1.00h	38.11e	86.26c
Ex-India 2	1.00h	25.52g	69.22d
SE ±		2.45	

Means within a column or row of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT.

Table 4.59: Interaction between P rates and Varieties on number of capsules per raceme of four castor varieties, 2006, 2007 and 2008 wet seasons (combined) at Samaru

	Number of capsules per raceme P rates (kg ha^{-1})		
Varieties	**0**	**7.92**	**15.84**
Ex-Brazil 1	39.70h	80.85d	115.67b
Ex-Brazil 2	51.56fg	101.59e	134.19a
Ex-India 1	1.00i	49.22g	75.15e
Ex-India 2	1.00i	37.37h	57.37f
SE ±		2.45	

Means within a column or row of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT.

with all the varieties, number of capsules per raceme increased significantly as the rates of P from 0 – 15. 84 kg ha^{-1} were increased.

At all levels of applied P, Ex- Brazil 2 produced the highest number of capsule per raceme at 0 kg P ha^{-1}, Ex- Brazil 1 was next to ex- Brazil 2 in producing significantly higher number of capsule per raceme while there was no significant difference between results produced by the two Indian varieties.

At 7.92 and 15.84 kg P ha^{-1}, the trend was similar except that Ex- India 1 had more number of capsules than Ex- India 2. The highest number of capsules per raceme was produced by Ex- Brazil 2 with 15.84 kg P ha^{-1} while the least was observed in the untreated control with the Indian varieties.

4.2.6 Number of racemes per plant

Result of effect of N, P and variety on number of racemes per plant in the period of study and the combined means (Table 4.60) indicated a progressive increase in number of racemes per plant with increase in the amount of N applied in all the three years and the combined analysis. A similar trend was observed with P application.

The effect of variety was similar in all the three years and the combined analysis. The Brazilian varieties produced more number of racemes per plant

compared with their Indian counterpart varieties with Ex- Brazil 1 and Ex- India 1 producing the highest number of capsules from each group respectively. However, result produced by the two Indian varieties in 2007 were comparable statistically. Only the interaction between N and P and N and variety were significant when the combined result was analysed.

In Table 4.61 the interaction between N and P on number of racemes per plant of four castor varieties showed that there was a steady increase in number of racemes per plant as the rates of N also increased across the different levels of P. At 0 kg N ha^{-1}, varying P levels did not influence any change in number of racemes per plant, however at higher N rates, each increase in levels of P significantly increased number of racemes per plant. The combination of 120 kg N + 15.84 kg P ha^{-1} produced the highest number of racemes per plant, while the lowest was produced by the control experiments.

The effect of interaction between N and variety in Table 4.61 on number of racemes per plant of four castor varieties in the combined analysis indicated that irrespective of variety, increase in N rates significantly increased number of racemes per plant. At 0 kg N ha^{-1}, the two Brazilian and the their Indian counterpart varieties each produced comparable number of racemes per plant. Also at 60 kg N ha^{-1}, the Indian varieties had comparable results that were statistically lower than Ex- Brazil 2.At the highest N rate, Ex-Brazil 2 was next to Ex- Brazil 1 in producing significantly higher number of racemes while Ex- Indian 2 produced the least.

4.2.7. Length of raceme

Result of effect of N, P and variety on length of raceme in all the three years and the combined analysis (Table 4.62) revealed that varying the rates of N gave a significant increase in length of racemes. A similar trend was recorded for P application except in 2007 when increase beyond 7.92 kg P ha^{-1} did not affect the length of racemes.

Table 4.60: Effects of N and P rates on number of racemes per plant of four castor varieties at Samaru, 2006, 2007, 2008 wet seasons and combined

Treatment	Number of racemes per plant 2006	2007	2008	Combined
Nitrogen (N) (kgha^{-1})				
0	1.00c	1.44c	1.81c	1.42c
60	2.61b	3.28b	3.61b	3.17b
120	4.19a	5.39a	6.83a	5.47a
SE ±	0.35	0.45	0.28	0.38
Phosphorus (P) (kgha^{-1})				
0	1.25c	1.83c	2.22c	1.77c
7.92	2.72b	3.36b	3.81b	3.30b
15.84	3.83a	4.92a	6.22a	4.99a
SE ±	0.35	0.45	0.28	0.36
Varieties (V)				
Ex-Brazil 1	3.15a	4.33a	5.22a	4.23a
Ex-Brazil 2	2.78b	3.81b	4.70b	3.77b
Ex-India 1	2.44c	2.81c	3.52c	2.93c
Ex- India 2	2.04d	2.52c	2.89d	2.48d
SE ±	0.35	0.45	0.28	0.36
Interaction				
N X P	NS	NS	NS	*
N X V	NS	NS	NS	*
P X V	NS	NS	NS	NS
N X P X V	NS	NS	NS	NS

Means within a column of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT

NS = Not significant

* = Significant at $P \leq 0.05$

Table 4.61: Interaction between N and P rates and varieties and N on number of racemes per plant of four castor varieties, 2006, 2007 and 2008 wet seasons (combined) at Samaru

	Number of racemes per plant N rates (kg ha^{-1})		
	0	**60**	**120**
P rates (kg ha^{-1})			
0	1.19g	1.72f	2.39e
7.92	1.47fg	3.11d	5.31b
15.84	1.58f	4.67c	8.72a
SE±		0.1	
Varieties			
Ex-Brazil 1	1.93g	4.07d	6.70a
Ex-Brazil 2	1.74g	3.63e	5.93b
Ex-India 1	1.00i	2.63f	5.15c
Ex-India 2	1.00i	2.33f	4.11d
SE ±		0.13	

Means within a column or row of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT.

The varietal effect in 2006 indicated that the Brazilian varieties had longer length of raceme per plant compared to the Indian counterpart varieties with Ex- Brazil 2 and Ex- India 1 having the highest values in each group. In 2007, the three varieties produced significantly higher but similar length of racemes relative to Ex- India 2. In 2008 and the combined, Ex-Brazil 1 followed by its counterpart variety Ex-Brazil 2 had the highest length in raceme. The least was recorded for Ex-India 1.

First order of interaction between N and P and also N and variety were significant in the combined analysis. Table 4.63 shows result of interaction between N and P on length of raceme. When result of the three years was combined, considering the different N fertilizer rates, at each level of P, the interaction effect showed that each increase in N rate caused an increase in length of racemes. Similarly at each N P level, significant increases in length of raceme were noted for each rise in the level of N except at 0 kg N ha^{-1} where results produced at 7.92 and 15.84 P kg ha^{-1} were statistically at per. The highest level of N and P combinations produced the longest raceme length per plant while the shortest raceme was attributed to untreated controlled plots.

Result of interaction between N and variety on length of raceme of four castor varieties at the combined analysis (Table 4.63) revealed significant increases in length of racemes per plant with each increase in N levels. At 0 kg N ha^{-1}, the Brazilian and the Indian varieties each had similar length of raceme.

However, at 60 and 120 kg N ha^{-1}, Ex-India 1 had significantly lower raceme length relative to the other three varieties that had comparable result.

Table 4.62: Effects of N and P on length of raceme of four castor varieties at samaru 2006, 2007, 2008 wet seasons and combined

Treatments	Length of raceme per plant (cm) 2006	2007	2008	Combined
Nitrogen (N) ($kgha^{-1}$)				
0	1.00c	0.06c	3.24c	1.43c
60	0.39b	8.89b	11.91b	7.06b
120	1.67a	12.04a	15.19a	9.63a
SE ±	0.12	0.52	0.17	0.36
Phosphorus (P) ($kgha^{-1}$)				
0	0.15c	3.94b	5.88c	3.32c
7.92	0.55b	8.77a	11.71b	7.01b
15.84	1.41a	9.22a	12.74a	7.79a
SE ±	0.12	0.52	0.17	0.36
Varieties (V)				
Ex-Brazil 1	0.66b	7.54ab	11.84a	6.68a
Ex-Brazil 2	1.18a	7.78a	10.83b	6.38b
Ex-India 1	0.53c	7.12ab	8.29d	5.21d
Ex- India 2	0.46d	6.80b	9.49c	5.91c
SE ±	0.12	0.52	0.17	0.36
Interaction				
N X P	NS	NS	NS	*
N X V	NS	NS	NS	*
P X V	NS	NS	NS	NS
N X P X V	NS	NS	NS	NS

Means within a column of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DNMRT

NS = Not significant

* = Significant

The 120 kg N ha^{-1} treatment produced the longest length of raceme while 0 kg N ha^{-1} gave the shortest.

4.2.8 Seed yield per hectare

The effect of N, P and variety of castor on seed yield per hectare in 2006, 2007, 2008 and the combined are presented in Table 4.64. The result showed that there was a consistent increase in yield with each increase in N levels. Similarly, every increase in P rates caused significant increase in seed yield except in 2006 when further increase beyond 7.92 kg P ha^{-1} resulted in no change in the yield of castor.

Variety Ex- Brazil 1 produced the best yield in castor all through the three years and the combined analysis. However, it was statistically comparable with yield produced by Ex- Brazil 2 in 2006, 2007 and 2008. This was followed by Ex-India 1 while the lowest yield obtained by Ex- India 2 all through the three years and the combined. Interaction effects between N and P, N and variety and also P and variety were observed to be significant when result of the three years were combined and analysed. The effect of interaction between N and P on seed yield per hectare in the combined analysis (Table 4.65) showed that the yield of castor produced per hectare increases steadily with each application of N irrespective of the quantity of applied P.

At constant N levels, increase in P rate above 7.92 kg ha^{-1} did not lead to any significant increase in yield when N level was at 0 kg ha^{-1}. At higher N rates however, each increase in P rates increased seed yield per hectare. The highest yield was obtained with the highest application of N and P rates while reverse was the case with plot that received neither N nor P.

Table 4.63: Interaction between N and P rates and varieties and N on length of raceme of four castor varieties, 2006, 2007 and 2008 wet seasons (combined) at Samaru

	Length of raceme (cm) N rates (kg ha^{-1})		
P rates (kg ha^{-1})	**0**	**60**	**120**
0	0.67h	2.23f	7.08e
7.92	1.71g	9.14d	10.18b
15.84	1.92g	9.81c	11.64a
SE+		0.15	
Varieties			
Ex-Brazil 1	2.28e	7.53c	10.23a
Ex-Brazil 2	2.12e	7.27c	9.75a
Ex-India 1	0.67f	6.39d	8.57b
Ex-India 2	0.67f	7.06c	9.99a
SE ±		0.17	

Means within a column or row of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT.

Table 4.64: Effects of N and P rates on seed yield per hectare of four castor varieties at Samaru, 2006, 2007, 2008 wet seasons and combined

Treatments	Seed yield (kg/ha) 2006	2007	2008	Combined
Nitrogen (N) (kgha^{-1})				
0	156.53c	148.11c	163.03c	155.89c
60	177.67b	202.56b	204.19b	194.81b
120	221.69a	242.58a	279.28a	247.85a
SE ±	1.04	1.21	0.98	1.06
Phosphorus (P) (kgha^{-1})				
0	172.06b	181.61c	182.89c	178.85c
7.92	189.25a	201.25b	216.17b	202.22b
15.84	194.53a	210.39a	247.44a	217.45a
SE ±	1.04	1.21	0.98	1.06
Varieties (V)				
Ex-Brazil 1	194.63a	212.48a	225.33a	210.81a
Ex-Brazil 2	190.89ab	204.41ab	219.19ab	204.83b
Ex-India 1	184.07b	195.56b	215.56b	198.40c
Ex- India 2	171.59c	178.56c	201.93c	184.03d
SE ±	0.90	1.04	0.85	1.06
Interaction				
N X P	NS	NS	NS	*
N X V	NS	NS	NS	*
P X V	NS	NS	NS	*
N X P X V	NS	NS	NS	NS

Means within a column of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT

NS = Not significant

* = Significant at $P \leq 0.05$

Interaction effect on N and variety in Table (4.65) indicated that with each variety, a significantly higher yield per hectare was obtained when the amount of applied N was each time increased. The Brazilian varieties at 0 kg N ha^{-1} did not produce significantly different yields of seed, however, this result was statistically higher than that of Ex-India 1, which was in turn higher than Ex-India 2. At 60 kg N ha^{-1}, Ex-Brazil 2 and Ex-India 1 that are the small seeded varieties had comparable seed yields that were lower and higher than that of Ex-Brazil 1 and Ex-India 2 respectively. At 120 kg N ha^{-1}, the two Brazilian varieties produced statistically similar yields which were the highest while the lowest yield was obtained by Ex-India 2 at 0 kg N ha^{-1}.

Interaction between P and variety on seed yield per hectare at the combined analysis (Table 4.66) showed that there was a significant increase in seed yield with increase in application of P rates in all the castor varieties used in this investigation. At 0 kg P ha^{-1} the three varieties produced comparable results that were higher than that of Ex-India 2. At 7.92 kg P ha^{-1}, the small seeded varieties i.e. Ex-Brazil 2 and Ex-India 1 produced comparable yields that were lower but higher than Ex-brazil 1 and Ex-Brazil 2 respectively. At 15.84 kg ha^{-1}, the two Brazilian varieties had statistically similar seed yield relative to the Indian varieties where higher seed yields was recorded for Ex-India 1 relative to Ex-India 2.

4.2.9 Calcium (Ca) concentration in castors leaves

The effect of N, P and variety on the concentration of Ca in castor leaves (Table 4.67) in 2006, 2007, 2008 and the combined analysis indicates that in 2006 and the combined analysis, each increase in N resulted in a significant increase in Ca leaf

Table 4.65: Interaction between N and P rates and varieties and N on seed yield/ha of four castor varieties, 2006, 2007 and 2008 wet seasons (combined) at Samaru

	Seed yield (kg ha^{-1}) N rates (kg ha^{-1})		
	0	**60**	**120**
P rates (kg ha^{-1})			
0	149.11g	175.56e	211.89c
7.92	160.67f	197.75d	248.25b
15.84	157.89f	211.11c	283.42a
SE±		2.08	
Varieties			
Ex-Brazil 1	183.89e	216.78b	231.78a
Ex-Brazil 2	182.67e	206.52c	225.30a
Ex-India 1	188.15f	198.11cd	216.93b
Ex-India 2	168.70g	187.48e	195.89de
SE ±		2.09	

Means within a column or row of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT.

Table 4.66: Interaction between P rates and Varieties on seed yield/ha of four castor varieties, 2006, 2007 and 2008 wet seasons

	Seed yield (kg/ha^{-1}) P rates (kg ha^{-1})		
Varieties	**0**	**60**	**120**
Ex-Brazil 1	162.11f	206.33d	264.00a
Ex-Brazil 2	157.78f	197.22e	259.48a
Ex-India 1	157.07f	195.89e	242.22b
Ex-India 2	146.59g	179.78f	225.70c
SE ±		2.09	

Means within a column or row of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT.

content. In 2007 and 2008, an increase beyond 60 kg N ha^{-1} was able to influence an increase in Ca leaf content.

Influence of P was such that in 2006 and 2008 each increase in P led to a significant increase in Ca content of the leaves. In 2007, varying P levels did not cause any change in the quantity of Ca detected in Castor leaves. When the results were combined, application of 7.92 kg P ha^{-1} caused a significant increase beyond which no further increase was noted in Ca deposition rate in castor leaves. Varietal effect showed that Ex-Brazil 2 had the highest quantity of Ca deposited in their leaves. This result was however comparable with Ex-Brazil 1 and Ex-India 1 in 2007 and with Ex-India 1 in the combined analysis.

The big seeded varieties i.e. Ex-Brazil 1 and Ex-India 2 had statistically similar leaf Ca in the combined analysis, a similar result was recorded for the small seeded varieties in the same year. The lowest Ca was recorded for Ex-India 2 in 2006 and 2008 wet seasons. None of the three first orders or the second order of interaction was significant in all the three years and the combined analysis.

4.2.10 Magnesium (Mg) concentration in castor leaves

Effect of N, P and variety on magnesium content of leaves in the three years of study and the combined analysis (Table 4.68) showed that Mg concentration in castor leaves increased as a result of increase in application of N.

The application of increased quantity of P also resulted in a similar trend. The highest rates of N and P produced plants with the highest Mg leaf content.

Table 4.67: Effects of N and P rates on Calcium (Ca) concentration in leaves of four castor varieties at Samaru 2006, 2007 and 2008 wet seasons

Treatment	Calcium concentration in leaves (%) 2006	2007	2008	Combined
Nitrogen (N) ($kgha^{-1}$)				
0	0.54c	0.54b	0.54b	0.54c
60	0.56b	0.56ab	0.56b	0.56b
120	0.58a	0.57a	0.59a	0.58a
SE ±	0.01	0.07	0.01	0.04
Phosphorus (P) ($kgha^{-1}$)				
0	0.55c	0.55	0.55c	0.55c
7.92	0.56b	0.57	0.57b	0.57a
15.84	0.57a	0.56	0.58a	0.57a
SE ±	0.01	0.07	0.01	0.04
Varieties (V)				
Ex-Brazil 1	0.55c	0.55ab	0.55c	0.55b
Ex-Brazil 2	0.59a	0.57a	060a	0.59a
Ex-India 1	0.58b	0.58a	0.58b	0.58a
Ex- India 2	0.52d	0.53b	0.53d	0.53b
SE ±	0.01	0.07	0.01	0.04
Interaction				
N X P	NS	NS	NS	NS
N X V	NS	NS	NS	NS
P X V	NS	NS	NS	NS
N X P X V	NS	NS	NS	NS

Means within a column of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT

NS = Not significant

* = Significant at $P \leq 0.05$

Table 4.68: Effects of N and P rates on Magnesium (Mg) concentration in leaves of four castor varieties at Samaru, in 2006, 2007 and 2008 wet seasons.

Treatment	Magnesium concentration in leaves (%) 2006	2007	2008	Combined
Nitrogen (N) ($kgha^{-1}$)				
0	0.45c	0.45c	0.45c	0.45c
60	0.46b	046b	0.46b	0.46b
120	0.48a	0.48a	0.48a	0.48a
SE ±	0.01	0.01	0.01	0.01
Phosphorus (P) ($kgha^{-1}$)				
0	0.46c	0.46c	0.46c	0.46c
7.92	0.47b	0.47b	0.47b	0.47b
15.84	0.47a	0.47a	0.47a	0.47a
SE ±	0.01	0.01	0.01	0.01
Varieties (V)				
Ex-Brazil 1	0.47b	0.47b	0.47b	0.47b
Ex-Brazil 2	0.48a	0.48a	0.48a	0.48a
Ex-India 1	0.46c	0.46c	0.46c	0.46c
Ex- India 2	0.45d	0.45d	0.45d	0.45d
SE ±	0.01	0.01	0.01	0.01
Interaction				
N X P	NS	NS	NS	NS
N X V	NS	NS	NS	NS
P X V	NS	NS	NS	NS
N X P X V	NS	NS	NS	NS

Means within a column of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT

NS = Not significant

* = Significant at $P \leq 0.05$

Amongst the varieties tested, Ex-Brazil 2 consistently produced plants with highest Mg concentration in all the three years and the combined followed by variety Ex-Brazil 1. Ex-India 2 had significantly the lowest Mg concentration relative to the other three varieties. None of the interactions was significant all through the trial period.

4.2.11 Nitrogen (N) concentration in castor leaves

The effects of N, P and variety on N content of leaves during the period of this investigation and the combined analysis is shown in Table 4.69. The result indicated that increasing N rates gave a significant increase in N content of castor leaves. A similar result was obtained with each increase in P rates.

Amongst the varieties evaluated Ex- Brazil 2 which is a small seeded variety produced the highest N concentration all through the three years and the combined means. This was followed by another small seeded variety Ex-India 1. Amongst the big seeded varieties, Ex-Brazil 1 significantly produced plants with more N concentration than Ex-India 2.Neither the first nor the second order of interaction was significant in the whole trail period.

4.2.12 Oil content of castor seeds

Effects of N, P rates and variety on oil content of castor seeds in the three years of study and the combined analysis (Table 4.70) showed that each increase in N led to a significant increases in oil content of castor seeds. Similarly increasing quantity of P yielded the same result. It was observed that the more the N and P rates, the more the oil deposit in castor.

Table 4.69: Effects of N and Phosphorus rates on Nitrogen (N) concentration in leaves of four castor varieties at Samaru, 2006, 2007 and 2008 wet seasons

Treatment	Nitrogen concentration in leaves (%) 2006	2007	2008	Combined
Nitrogen (N) ($kgha^{-1}$)				
0	2.22c	2.22c	2.23c	2.22c
60	3.29b	3.30b	3.28b	3.29b
120	4.20a	4.23a	4.36a	4.26a
SE ±	0.04	0.04	0.06	0.06
Phosphorus (P) ($kgha^{-1}$)				
0	3.15c	3.16c	3.18c	3.16c
7.92	3.23b	3.24b	3.28b	3.25b
15.84	3.34a	3.36a	3.41a	3.37a
SE ±	0.04	0.04	0.06	0.05
Varieties (V)				
Ex-Brazil 1	3.18c	3.20c	3.20c	3.21c
Ex-Brazil 2	3.39a	3.40a	3.42a	3.40a
Ex-India 1	3.34b	3.34b	3.35b	3.34b
Ex- India 2	3.05d	3.07d	3.12d	3.08d
SE ±	0.04	0.04	0.06	0.05
Interaction				
N X P	NS	NS	NS	NS
N X V	NS	NS	NS	NS
P X V	NS	NS	NS	NS
N X P X V	NS	NS	NS	NS

Means within a column of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT

NS = Not significant

* = Significant at $P \leq 0.05$

Variety Ex-Brazil 2 consistently produced seeds with the highest oil content followed by Ex-India 2 both of which are small seeded. Ex-Brazil 1 that is a big seeded variety had comparable result with another big seeded Ex-India 2 variety in 2007 and 2008. The least seed oil deposition was observed with Ex-India 2 in 2006 and the combine analysis. Interactions between N and P, N and variety and also P and variety were significant when results of the three years was combined.

The interaction between N and P on oil content of seeds of four castor varieties in the combine means (Table 4.71) revealed that oil deposit in castor seeds improves with each increase in the amount of N at each level of applied P. At 0 kg N ha^{-1}, varying P rates did not have any influence on changing the quantity of oil deposited, however at higher levels of N, each increase in P rate led to a significant increase in oil content of castor seeds. Result of interaction between N and variety on oil content of seeds of castor in the combined means (Table 4.71) showed that with each increase in N rates, oil deposit in seeds of all the four varieties also improves.

At all levels of N, Ex-Brazil 2, a small seeded variety had the highest quantity of oil deposition. This was followed by Ex-India 1 which is a small seeded variety at 0 and 120 kg N ha^{-1}. Amongst the big seeded varieties at these same two levels, Ex-Brazil 1 produced seeds with more oil then Ex-India 2. However, comparable oil deposition was observed with Ex-Brazil 1 and Ex-India 1 at 60 kg N ha^{-1}. Interaction between P and variety on oil content of castor seeds analysed from the combined result in (Table 4.72) revealed that increase in P rate up to 7.92 kg ha^{-1} improves oil content in Ex-Brazil 1 variety. However, beyond this rate, there was no significant increase observed.

Table 4.70: Effect of Nitrogen and Phosphorus rates on Oil content in seeds of four castor varieties at Samaru, 2006, 2007 and 2008 wet seasons

Treatment	Oil Content (%) 2006	2007	2008	Combined
Nitrogen (N) (kgha^{-1})				
0	41.91c	42.21c	42.61c	42.25c
60	43.45a	43.97b	44.44b	43.95b
120	42.58b	46.95a	48.18a	46.91a
SE ±	0.09	0.09	0.12	0.01
Phosphorus (P) (kgha^{-1})				
0	42.55c	42.89c	43.42c	42.95c
7.92	43.69a	44.75b	45.20b	44.55b
15.84	44.70b	45.49a	46.42a	45.61a
SE ±	0.09	0.09	0.12	0.01
Varieties (V)				
Ex-Brazil 1	43.12c	43.50c	43.96c	43.53c
Ex-Brazil 2	45.08a	46.03a	47.34a	46.15a
Ex-India 1	44.01b	44.77b	45.40b	44.73b
Ex- India 2	42.38d	43.20c	43.61c	43.07d
SE ±	0.09	0.09	0.12	0.01
Interaction				
N X P	NS	NS	NS	*
N X V	NS	NS	NS	*
P X V	NS	NS	NS	*
N X P X V	NS	NS	NS	NS

Means within a column of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT

NS = Not significant

* = Significant at $P \leq 0.05$

Table 4.71: Interaction between N and P rates and varieties and N rates on oil content of seeds of four castor varieties, 2006, 2007 and 2008 wet seasons at Samaru

	Oil Content (%) N rates (kg ha^{-1})		
	0	**60**	**120**
P rates kg ha^{-1}			
0	41.68f	43.26e	43.92d
7.92	42.24f	43.91d	47.49b
15.84	42.82f	44.69c	49.31a
SE ±		0.11	
Varieties			
Ex-Brazil 1	41.40h	43.67f	45.52c
Ex-Brazil 2	44.00f	44.99e	49.46a
Ex-India 1	42.86g	44.04f	47.28b
Ex-India 2	40.72i	43.10g	45.37de
SE ±		0.13	

Means within a column or row of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT.

With all the other three varieties however, each increase in the amount of P resulted in increased oil content in castor. At 0 kg P ha^{-1}, Ex-Brazil 1 and Ex-India 2 produced results that were statistically at par but lower than Ex-India 1. The highest oil quantity was found in Ex-Brazil 2. At 7.92 kg P ha^{-1}, also Ex-Brazil 2 produced the best result followed by Ex-India 1 and then Ex-Brazil 1. The least oil content was recorded for Ex-India 2. A similar trend was noted at 15.84 kg P ha^{-1}, except that the two big seeded varieties, Ex-Brazil 1 and Ex-India 2 produced comparable oil content in their seeds.

4.2.13 Phosphorus (P) concentration in castor leaves

The effects of N, P and variety on P concentration in leaves of castor in the three years of study and the combined analysis in (Table 4.73) showed that as the quantity of N was increased each time, the rate of P content in castor leaves also increases. A similar trend was noted for increased application of P.

Varietal effect indicated that the small seeded varieties had more P in their leaves compared with the big seeded varieties with the result that Ex-Brazil 2 and Ex-India 2 produced the highest and lowest P values, respectively amongst the small seeded. However, in 2006 and 2007, Ex-Brazil 1 and Ex-India 1 produced statistically similar P in leaves of castor. Amongst the big seeded varieties, Ex-Brazil 1 had more P than Ex-India 2 in all the three years and the combined analysis. Neither the first nor the second order of interaction was significant all through the period of this experimental trial.

Table 4.72: Interaction between P rates and Varieties on oil content of seeds of four castor varieties, 2006, 2007 and 2008 wet seasons

	Oil Content (%) P rates (kg ha^{-1})		
Varieties	**0**	**7.92**	**15.84**
Ex-Brazil 1	42.36g	43.69e	44.54e
Ex-Brazil 2	44.44e	46.33b	47.68a
Ex-India 1	43.29f	44.99d	45.90c
Ex-India 2	41.71g	43.18f	44.31e
SE ±		0.13	

Means within a column or row of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT.

Table 4.73: Effects of N and P rates on phosphorous (P) concentration in leaves of four castor varieties at Samaru, 2006, 2007 and 2008 wet seasons

Treatment	Phosphorous concentration in leaves (%) 2006	2007	2008	Combined
Nitrogen (N) ($kgha^{-1}$)				
0	0.48c	0.48c	0.48c	0.48c
60	0.51b	0.51b	0.52b	0.51b
120	0.53a	0.54a	0.55a	0.54a
SE ±	0.01	0.01	0.01	0.01
Phosphorus (P) ($kgha^{-1}$)				
0	0.49c	0.50c	0.50c	0.50c
7.92	0.51b	0.51b	0.52b	0.51b
15.84	0.52a	0.53a	0.53a	0.52a
SE ±	0.01	0.01	0.01	0.01
Varieties (V)				
Ex-Brazil 1	0.47b	0.47b	0.48c	0.47c
Ex-Brazil 2	0.60a	0.60a	0.61a	0.60a
Ex-India 1	0.54b	0.54b	0.55b	0.54b
Ex- India 2	0.43d	0.43d	0.44d	0.43d
SE ±	0.01	0.01	0.01	0.01
Interaction				
N X P	NS	NS	NS	NS
N X V	NS	NS	NS	NS
P X V	NS	NS	NS	NS
N X P X V	NS	NS	NS	NS

Means within a column of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT

NS = Not significant

4.2.14 Potassium (K) concentration in castor leaves

Effects of N, P and variety on K concentration in leaves of castor in Table 4.74 during 2006, 2007, 2008 and the combined analysis showed that each increase in amount of N caused significant increases in K deposit in leaves of castor. However, increase in N beyond 60 kg ha^{-1} in 2008 did not further increase K content. Similarly, each increase in P resulted in increased in K in all the three years and combined.

The effect of variety revealed that Ex-Brazil 2 had the highest quantity of K is their leaves. This was followed by statistically comparable result obtained by Ex-Brazil 1 and Ex-India 1 throughout the three years and the combined analysis. The least K content was recorded for Ex-India 2.None of the interactions was significant in 2006, 2007, 2008 and the combined analysis.

4.2.15 Sodium (Na) concentration in castor leaves

Responses of castor to the effect of N, P and variety on Na concentration in the leaves of four castor varieties (Table 4.75) in the three years and their combined mean showed each increase in N rate significantly increased Na content of leaves castor in all the years and their mean. Similarly the same trend was recorded for each increase in P rates across all the three years and their mean values.

Varietal response indicated that a big seeded variety Ex-Brazil 1 had higher Na leaf content than the other big seeded variety Ex-India 2. Both produced plants with higher Na content compared to varieties with small seeds. Ex-India 1 produced the least Na leaf content amongst the small seeded varieties. Neither the first nor the second order of interaction was significant throughout the three cropping seasons and the combined analysis.

Table 4.74: Effects of N and P rates on Potassium (K) concentration in leaves of four castor varieties at Samaru, 2006, 2007 and 2008 wet seasons

Treatment	Potassium concentration in leaves (%) 2006	2007	2008	Combined
Nitrogen (N) ($kgha^{-1}$)				
0	0.56b	0.56b	0.56b	0.56b
60	0.60a	0.60a	0.60a	0.60a
120	0.62a	0.63a	0.63b	0.63a
SE ±	0.01	0.01	0.01	0.01
Phosphorus (P) ($kgha^{-1}$)				
0	0.57c	0.57c	0.58c	0.57c
7.92	0.60b	0.60b	0.60b	0.60b
15.84	0.61a	0.62a	0.62a	0.62a
SE ±	0.01	0.01	0.01	0.01
Varieties (V)				
Ex-Brazil 1	0.59b	0.59b	0.59b	0.59b
Ex-Brazil 2	0.65a	0.65a	0.66a	0.65a
Ex-India 1	0.59b	0.59b	0.59b	059b
Ex- India 2	0.56c	0.56c	0.56c	0.56c
SE ±	0.01	0.01	0.01	0.01
Interaction				
N X P	NS	NS	NS	NS
N X V	NS	NS	NS	NS
P X V	NS	NS	NS	NS
N X P X V	NS	NS	NS	NS

Means within a column of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT

NS = Not significant

Table 4.75: Effects of N and P rates on Sodium (Na) concentration in leaves of four castor varieties at Samaru, 2006, 2007 and 2008 wet seasons

Treatment	Sodium concentration in leaves (%) 2006	2007	2008	Combined
Nitrogen (N) ($kgha^{-1}$)				
0	0.29c	0.29c	0.29c	0.29c
60	0.30b	0.30b	0.31b	0.30b
120	0.31a	0.31a	0.32a	0.31a
SE ±	0.01	0.01	0.01	0.01
Phosphorus (P) ($kgha^{-1}$)				
0	0.29c	0.29c	0.29c	0.29c
7.92	0.30b	0.30b	0.31b	0.30b
15.84	0.31a	0.31a	0.31a	0.31a
SE ±	0.01	0.01	0.01	0.01
Varieties (V)				
Ex-Brazil 1	0.34a	0.33a	0.34a	0.34a
Ex-Brazil 2	0.28c	0.28c	0.28c	0.28c
Ex-India 1	0.27d	0.27d	0.27d	0.27d
Ex- India 2	0.32b	0.32b	0.32b	0.32b
SE ±	0.01	0.01	0.01	0.01
Interaction				
N X P	NS	NS	NS	NS
N X V	NS	NS	NS	NS
P X V	NS	NS	NS	NS
N X P X V	NS	NS	NS	NS

Means within a column of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT

NS = Not significant

4.2.16 Sulphur (S) concentration in castor leaves

Result of effect of N, P and variety on S concentration in leaves of castor throughout the three years of this investigation and the combined analysis (Table 4.76) showed that each year, significantly higher S rates were produced with each increase in N rates except in 2006 when application of more N higher than 60 kg N ha^{-1} did not cause a resultant increase. Also, each increase in P resulted to significant increases in S content of leaf in all the three years and the combined result.

Varietal response showed that Ex-Brazil 1 has produced plants with the highest Na concentration followed by Ex-India 2 both of which are big seeded. Amongst the small seeded, Ex-Brazil 2 produced significantly higher Na in leaves of castor plants compared with Ex-India 1 that had the least. None of the interactions was significant all through the period of this research study.

4.3 Correlation Between Growth, Yield and Yield Attributes of Castor

In all the years of the study and in the combined analysis (Tables 4.77, 4.78, 4.79 and 4.80) castor seed yield per hectare was positively and significantly correlated with oil content of seeds, plant height at 16 WAS, number of leaves at 16 WAS, number of branches at 16 WAS, plant dry weight at 16 WAS and number of racemes per plant.

There was also a positive and significant correlation between castor seed yield and capsule weight per plant, CGR at 16 WAS, diameter of capsule and LAI at 16 WAS in 2008 and the combined analysis. A positive and significant correlation was observed between castor seed yield and days to 50% first flowering and raceme length per plant (2006, 2008 and in combined) and number of capsules per raceme (2007 and combined).

Table 4.76: Effects of N and P rates on Sulphur (S) concentration in leaves of four castor varieties at Samaru, 2006, 2007 and 2008 wet seasons

Treatment	Sulphur concentration in leaves (%) 2006	2007	2008	Combined
Nitrogen (N) ($kgha^{-1}$)				
0	0.25c	0.25c	0.25c	0.25c
60	0.26b	0.26b	0.26b	0.26b
120	0.27b	0.27a	0.27a	0.27a
SE ±	0.01	0.01	0.01	0.01
Phosphorus (P) ($kgha^{-1}$)				
0	0.25c	0.25c	0.25c	0.25c
7.92	0.26b	0.26b	0.26b	0.26b
15.84	0.26a	0.27a	0.27a	0.27a
SE ±	0.01	0.01	0.01	0.01
Varieties (V)				
Ex-Brazil 1	0.30a	0.31a	0.31a	0.31a
Ex-Brazil 2	0.22c	0.22c	0.22c	0.22c
Ex-India 1	0.21d	0.21d	0.21d	0.21d
Ex- India 2	0.29b	0.29b	0.29b	0.29b
SE ±	0.01	0.01	0.01	0.01
Interaction				
N X P	NS	NS	NS	NS
N X V	NS	NS	NS	NS
P X V	NS	NS	NS	NS
N X P X V	NS	NS	NS	NS

Means within column of treatment followed by unlike letter(s) are significantly different at 5% level of probability using DMRT

NS = Not significant

Although not significant, NAR and 16 WAS was negatively correlated with castor seed yield per hectare in 2006, 2008 and in the combined analysis.

Relationship between oil content of castor seeds with plant height at 16 WAS, number of leaves at 16 WAS, number of branches at 16 WAS, plant dry weight at 16 WAS, capsule weight of plant, days to 50% first flowering, diameter of capsule and LAI at 16 WAS was positive and significant in all the three years and the combined analysis. The correlation matrix also showed that the correlation between the oil content of seeds and CGR at 16 WAS in 2006, 2008 and the combined analysis was significant and positive. Seeds oil content was also positively correlated with NAR at 16 WAS (2007), number of capsules per raceme (2006 and the combined analysis), number of racemes per plant (2006, 2007 and the combined analysis) and with length of raceme (2006, 2008 and the combined analysis). Although not significant, oil seed contents was negatively correlated with NAR in 2006 and 2008.

A positive and significant correlation was noted between plant height at 16 WAS and number of leaves at 16 WAS, number of branches at 16 WAS, plant dry weight at 16 WAS, CGR at 16 WAS, days to 50% first flowering, diameter of capsule and LAI at 16 WAS. It was also observed that relationship between plant height at 16 WAS and number of capsules per raceme and number racemes per plant in 2006 and the combined analysis was positive and significant.

In 2006, 2008 and the combined analysis a positive and significant correlation between plant height at 16 WAS and length of raceme per plant and also with capsule weight per plant (2008 and combined analysis). A negative but non significant correlation was

observed between plant height at 16 WAS and NAR at 16 WAS in 2006 and the combined analysis.

Number of leaves at 16 WAS was found to be positively and significantly correlated with plant dry weight at 16 WAS, CGR at 16 WAS, diameter of capsule and LAI at 16 WAS in all the years of the study and the combined analysis. There also exists a positive and significant correlation between number of leaves at 16 WAS and number of branches at 16 WAS in 2006, 2007 and the combined analysis. Relationship between number of leaves at 16 WAS and capsule weight of plant in 2006 and the combined analysis was also observed to be positive and significant. Number of leaves at 16 WAS was recorded to have a significant and positive correlation with days to 50% first flowering (2006, 2008 and the combined analysis), number of capsule per raceme (2008 and the combined) and length of raceme (2006 and 2008). In 2006 and the combined analysis, a negative but non significant correlation was noted between number of leaves at 16 WAS and NAR at 16 WAS.

Correlation matrix in the three years of this research study and the combined analysis showed that number of branches at 16 WAS was positively and significantly correlated with plant dry weight at 16 WAS, CGR at 16 WAS, diameter of capsule and LAI at 16 WAS. A positive and significant correlation was noted between number branches at 16 WAS with number of capsule per raceme and capsule weight of plant (combined analysis), NAR at 16 WAS (2007), days to 50% first flowering and length of racemes (2006, 2008 and the combined) and number of raceme per plant (2006 and the combined analysis). Although not significant, number of branches at 16 WAS was negatively correlated with NAR at 16 WAS in the combined analysis.

Results of correlation studies in 2006, 2007, 2008 and the combined analysis indicated that a positive and significant correlation exists between plant dry weight at 16 WAS and capsule weight of plant, CGR at 16 WAS, diameter of capsule, LAI at 16 WAS, number of capsules per raceme, length of raceme. Similarly, a positive and significant correlation exists between plant dry weight at 16 WAS and days to 50% first flowering (2006 and the combined analysis) and NAR at 16 WAS (2007).

Correlation studies between capsule weight of plant in the three years of this research investigation and the combined analysis revealed that a positive and significant correlation was noted with CGR at 16 WAS, days to 50% first flowering , diameter of capsule, LAI at 16 WAS, number of racemes per plant and raceme length per plant. It was also observed that capsule weight per plant and NAR at 16 WAS were positive and significantly correlated in 2007 and 2008 wet seasons while a negative but non significant correlation was observed in the combined analysis. A positive and significant correlation was recorded between capsule weight per plant and number of capsules per raceme in 2006, 2007 and 2008 wet seasons.

In the three years of this study and the combined analysis, it was observed that CGR at 16 WAS was positive and significantly correlated with days to 50% first flowering, diameter of capsule, LAI at 16 WAS, number of capsules per raceme, number of racemes per plant, and raceme length per plant while it was observed that CGR and 16 WAS was positively and significantly correlated with NAR at 16 WAS only in 2007, 2008 and the combined analysis.

There was a positive and significant correlation between days to 50% flowering and diameter of capsule, LAI at 16 WAS, number of capsules per raceme and number

of racemes per plant in all the period of this research study and the combined analysis. However a highly significant and positive correlation was noted in 2006, 2008 and the combined analysis between days to 50% first flowering and raceme length per plant while a negative and non significant correlation was recorded between days to 50% first flowering and NAR at 16 WAS in 2006, 2008 and the combined analysis.

In 2006, 2007, 2008 and the combined analysis, it was observed that a highly positive and significant correlation existed between diameter of capsule and LAI at 16 WAS, number of capsules per raceme, number of racemes per plant and length of raceme. In 2007 and 2008, a positive and significant correlation was recorded for diameter of capsule and NAR at 16 WAS.

A significant and positive correlation existed between LAI at 16 WAS and number of capsules per raceme, number of racemes per plant and raceme length per plant in all the three years and the combined analysis. Similarly, except in 2006, a positive and significant correlation was recorded between LAI at 16 WAS and NAR at 16 WAS during the period of this study and the combined analysis.

Net assimilation rate at 16 WAS was positively and significantly correlation with number of capsules per raceme and number of racemes per plant in the three years and the combined analysis. It was observed that only in 2007 a positive and significant correlation was recorded between NAR at 16 WAS and raceme length per plant while a negative and non significant correlation was observed between NAR at 16 WAS and raceme length per plant in 2006 and the combined analysis.

A highly significant and positive correlation was noted in all the period of

Table 4.77: Correlation matrix among some growth and yield attributes of four castor varieties in 2006 wet season

	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	V_{10}	V_{11}	V_{12}	V_{13}	V_{14}
V_1	1.0000													
V_2	0.7243**	1.0000												
V_3	0.8155**	0.7833**	1.0000											
V_4	0.7359**	0.6938**	0.8789**	1.0000										
V_5	0.7465**	0.7168**	0.8963**	0.9838**	1.0000									
V_6	0.8355**	0.8120**	0.9600**	0.8488**	0.8667**	1.0000								
V_7	0.1083	0.2627*	0.2135*	0.1892*	0.1758	0.2291*	1.0000							
V_8	0.1023	0.2611*	0.3168**	0.2855*	0.2783*	0.3180**	0.5482**	1.0000						
V_9	0.1866*	0.2871*	0.3456**	0.3304**	0.3320**	0.3688**	0.4610**	0.6681**	1.0000					
V_{10}	0.1336	0.2773*	0.3408**	0.2756*	0.2800*	0.3524**	0.5655**	0.8144**	0.8392**	1.0000				
V_{11}	0.1361	0.2955*	0.3354**	0.2864*	0.2752*	0.3494*	0.5950**	0.8733**	0.6780**	0.8254**	1.0000			
V_{12}	-0.0249	-0.0274	-0.0183	-0.0732	-0.0714	-0.0211	0.0442	0.0482	-0.0404	0.0107	0.0390	1.0000		
V_{13}	0.0633	0.2383*	0.2480*	0.1532	0.1449	0.2674*	0.5694**	0.8544**	0.5834**	0.8322**	0.8983**	0.0540	1.0000	
V_{14}	0.1118*	0.2766*	0.3061*	0.2218*	0.2182	0.2981*	0.6460**	0.8432**	0.6032**	0.8030**	0.8618**	0.0538	0.8995**	1.0000
V_{15}	0.1422**	0.2987*	0.3039*	0.2657*	0.2620*	0.3296**	0.6448**	0.7607**	0.8919**	0.8651**	0.8022**	-.0068	0.7537**	0.7910**

V1 = Seed yield per hectare
V2 = Oil content of seeds
V3 = Plant height at 16 WAS
V4 = Number of leaves at 16 WAS
V5 = Number of branches at 16 WAS
V6 = Plant dry weight at 16 WAS
V7 = Capsule weight per plant
V8 = Crop growth rate (CGR) at 16 WAS
V9 = Days to 50% flowering
V10 = Diameter of capsule
V11 = Leaf area index (LAI) at 16 WAS
V12 = Net assimilation rate (NAR) at 16 WAS
V13 = Number of capsules per raceme
V14 = Number of racemes per plant
V15 = length of raceme per plant

Table 4.78: Correlation matrix among some growth and yield attributes of four castor varieties in 2007 wet season

	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	V_{10}	V_{11}	V_{12}	V_{13}	V_{14}	V_{15}
V_1	1.0000														
V_2	0.7340**	1.0000													
V_3	0.6429**	0.7358**	1.0000												
V_4	0.7678**	0.7305**	0.7928**	1.0000											
V_5	0.6641**	0.7237**	0.8315**	0.9879**	1.0000										
V_6	0.6941**	0.7933**	0.8555**	0.8726**	0.8810**	1.0000									
V_7	0.0329	0.2023*	0.0612	0.1553	0.1514	0.1982*	1.0000								
V_8	0.1523	0.1852	0.2416*	0.2411*	0.2309**	0.2975*	0.5173**	1.0000							
V_9	0.0709	0.1869*	0.2131*	0.1755	0.1705	0.1841	0.3023*	0.3020*	1.0000						
V_{10}	0.1496	0.3932**	0.3313**	0.2911*	0.3029*	0.3511**	0.4417**	0.3528**	0.3843**	1.0000					
V_{11}	0.6678	0.2755*	0.2787*	0.2058*	0.2214*	0.3929**	0.4503**	0.6429**	0.2266*	0.2880*	1.0000				
V_{12}	0.0371	0.1912*	0.0968	0.1850	0.1872*	0.2823*	0.6774**	0.7600**	0.1774	0.3555**	0.6748**	1.0000			
V_{13}	0.0158**	0.1708	0.0916	0.1154	0.1082	0.2169*	0.6189**	0.7064**	0.3969**	0.4721**	0.5967**	0.8104**	1.0000		
V_{14}	0.0235*	0.2000*	0.1284	0.1442	0.1384	0.2492*	0.7209**	0.7683**	0.3784**	0.4514**	0.6097**	0.8575**	0.9106**	1.0000	
V_{15}	0.0053	0.0945	0.0939	0.1438	0.1426	0.2467*	0.5437**	0.7612**	0.1717	0.3313**	0.6103**	0.9065**	0.8805**	0.8656**	1.0000

V1 = Seed yield per hectare
V2 = Oil content of seeds
V3 = Plant height at 16 WAS
V4 = Number of leaves at 16 WAS
V5 = Number of branches at 16 WAS
V6 = Plant dry weight at 16 WAS
V7 = Capsule weight per plant
V8 = Crop growth rate (CGR) at 16 WAS
V9 = Days to 50% flowering
V10 = Diameter of capsule
V11 = Leaf area index (LAI) at 16 WAS
V12 = Net assimilation rate (NAR) at 16 WAS
V13 = Number of capsules per raceme
V14 = Number of racemes per plant
V15 = Length of raceme per plant

Table 4.79: Correlation matrix among some growth and yield attributes of four castor variation in 2008 wet season

	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	V_{10}	V_{11}	V_{12}	V_{13}	V_{14}	V_{15}
V_1	1.0000														
V_2	0.8401**	1.0000													
V_3	0.9235**	0.8310**	1.0000												
V_4	0.9031**	0.7966**	0.9068**	1.0000											
V_5	0.9103**	0.8020**	0.9151**	0.9971	1.0000										
V_6	0.9137**	0.7997**	0.9423**	0.9467**	0.9523**	1.0000									
V_7	0.1745*	0.2414*	0.1939*	0.1562	0.1506	0.2097*	1.0000								
V_8	0.2300*	0.2428*	0.2383*	0.2533*	0.2535*	0.3188**	0.5061**	1.0000							
V_9	0.1935*	0.2004*	0.1985*	0.1872*	0.1884*	0.1809	0.3214**	0.2857*	1.0000						
V_{10}	0.2346*	0.3037*	0.2423*	0.2295*	0.2248*	0.2606*	0.8198**	0.6033*	0.6858**	1.0000					
V_{11}	0.2527*	0.2873*	0.2727*	0.2717*	0.2714*	0.3260**	0.6631**	0.8849**	0.3332**	0.7335**	1.0000				
V_{12}	-0.0008	-0.0177	0.0134	0.1134	0.1002	0.1172	0.3903**	0.5300**	-0.1713	0.2400*	0.4560**	1.0000			
V_{13}	0.1371	0.1737	0.1685	0.1935*	0.1768	0.2127*	0.5782**	0.7717**	0.4436**	0.6548**	0.8376**	0.4143**	1.0000		
V_{14}	0.1338*	0.1707	0.1682	0.1752	0.1838	0.2287*	0.6893**	0.8737**	0.3235**	0.6920**	0.9095**	0.6249**	0.8738**	1.0000	
V_{15}	0.2922*	0.3348**	0.2851*	0.2686*	0.2682*	0.3195**	0.6695**	0.7024**	0.7306**	0.8987**	0.7873**	0.1671	0.7302**	0.7264**	1.0000

V1 = Seed yield per hectare
V2 = Oil content of seeds
V3 = Plant height at 16 WAS
V4 = Number of leaves at 16 WAS
V5 = Number of branches at 16 WAS
V6 = Plant dry weight at 16 WAS
V7 = Capsule weight per plant
V8 = Crop growth rate (CGR) at 16 WAS
V9 = Days to 50% flowering
V10 = Diameter of capsule
V11 = Leaf area index (LAI) at 16 WAS
V12 = Net assimilation rate (NAR) at 16 WAS
V13 = Number of capsules per raceme
V14 = Number of racemes per plant
V15 = Length of raceme per plant

Table 4.80: Correlation matrix among some growth and yield attributes of four castor varieties in 2006, 2007 and 2008 combined wet season

	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	V_{10}	V_{11}	V_{12}	V_{13}	V_{14}	V_{15}
V_1	1.0000														
V_2	0.7929**	1.0000													
V_3	0.7940**	0.7830**	1.0000												
V_4	0.8318**	0.7616**	0.8576**	1.0000											
V_5	0.7736**	0.7663**	0.8810**	0.9914**	1.0000										
V_6	0.8163**	0.8021**	0.9087**	0.8939**	0.9031**	1.0000									
V_7	0.1276*	0.2433**	0.1648*	0.1758*	0.1688*	0.2256**	1.0000								
V_8	0.0915**	0.2571**	0.2656**	0.2847**	0.2542**	0.3384**	0.5232**	1.0000							
V_9	0.1776*	0.2389**	0.2714**	0.2408**	0.2394**	0.2633**	0.3675**	0.4553**	1.0000						
V_{10}	0.2007**	0.3454**	0.3121**	0.2755**	0.2799**	0.3467**	0.5612**	0.5205**	0.5619**	1.0000					
V_{11}	0.3911*	0.2484**	0.2956**	0.2713**	0.2560**	0.3886**	0.5535**	0.6670**	0.4041**	0.5083**	1.0000				
V_{12}	-0.0397	0.0127	-0.0200	-0.0275	-0.255	0.0146	-0.0126	0.1249*	-0.0224	0.0649	0.1339*	1.0000			
V_{13}	0.1317*	0.2199**	0.1960**	0.1851**	0.1800*	0.2612**	0.5907**	0.7761**	0.4808**	0.5831**	0.7494**	0.1330*	1.0000		
V_{14}	0.1484*	0.2360**	0.2204**	0.2175**	0.2112**	0.2851**	0.6807**	0.8142**	0.4253**	0.5757**	0.7634**	0.1473*	0.8932**	1.0000	
V_{15}	0.2058**	0.2392**	0.2271**	0.2262**	0.2203**	0.2089**	0.4282**	0.5314**	0.4806**	0.3990**	0.4764**	-0.0289	0.5476**	0.5552**	1.0000

V1 = Seed yield per hectare
V2 = Oil content of seeds
V3 = Plant height at 16 WAS
V4 = Number of leaves at 16 WAS
V5 = Number of branches at 16 WAS
V6 = Plant dry weight at 16 WAS
V7 = Capsule weight per plant
V8 = Crop growth rate (CGR) at 16 WAS
V9 = Days to 50% flowering
V10 = Diameter of capsule
V11 = Leaf area index (LAI) at 16 WAS
V12 = Net assimilation rate (NAR) at 16 WAS
V13 = Number of seeds per capsule
V14 = Number of racemes per plant
V15 = Raceme length per plant

study and the combined analysis between number of capsules per raceme and number of racemes per plant and raceme length per plant during the period of this research investigation and the combined analysis. Number of racemes per plant was observed to be highly significant and positively correlated with raceme length per plant in 2006, 2007, 2008 and the combined analysis.

4.4 Path Coefficient Analysis and Percent Contribution of Growth and Yield Components to Seed Yield of Four Castor Varieties

The direct and indirect effects of some vegetative components on seed yield of castor in 2006, 2007, 2008 and the combined wet seasons are presented in Tables 4.81, 4.82, 4.83 and 4.84. The results revealed that out of the total correlation coefficient of 0.8155, 0.9235 and 0.7940 in 2006, 2008 and the combined analysis, the direct effect of plant height was positive and highest (0.8058, 0.5590 and 0.4416) respectively. In 2007, LAI exhibited the highest direct effect via all of the other growth components used in this analysis (0.5580). The next higher direct effect showed some variation in the sense that in 2006, 2007 and 2008, this was noted for number of branches/plant (0.0729, 0.4502 and 0.4009) respectively while this same effect was recorded for LAI in the combined analysis.

In the three years of the investigations and the combined data, it was observed that the least total correlation was exhibited by CGR, the least contributory direct but negative effect was exhibited by CGR in 2006, 2007 and the combined analysis (-0.1216, -0.4163 and -0.4163 respectively). Direct effect

Table 4.81: The direct and indirect contributions of yield and growth components of four castor varieties at 16 WAS in 2006

	Effect through				
Parameter	**Plant Height**	**Number of Branches**	**Crop Growth Rate**	**Leaf Area Index**	**Total Correlation**
Plant height	0.8058	0.0653	-0.0515	-0.0041	0.8155
Number of branches	0.7222	0.0729	-0.0452	-0.0034	0.7465
Crop growth rate	0.2553	0.0203	-0.1625	-0.0107	0.1023
Leaf area index	0.2703	0.0201	-0.1419	-0.0123	0.1361

Figures under lined represent the direct effects of the factor

Table 4.82: The direct and indirect contributions of yield and growth components of four castor varieties at 16 WAS in 2007 wet season.

	Effect through				
Parameter	**Plant Height**	**Number of Branches**	**Crop Growth Rate**	**Leaf Area Index**	**Total Correlation**
Plant height	0.1424	0.3743	-0.0294	0.1555	0.6429
Number of branches	0.1184	0.4502	-0.0281	0.1235	0.6641
Crop growth rate	0.0344	0.1040	-0.1216	0.1355	0.1523
Leaf area index	0.0397	0.0997	-0.0295	0.5580	0.6678

Figures under lined represent the direct effects of the factor

Table 4.83: The direct and indirect contributions of yield and growth components of four castor varieties at 16 WAS in 2008 wet season.

	Effect through				
Parameter	**Plant Height**	**Number of Branches**	**Crop Growth Rate**	**Leaf Area Index**	**Total Correlation**
Plant height	0.5590	0.3669	0.0030	-0.0054	0.9235
Number of branches	0.5115	0.4009	0.0032	-0.0053	0.9103
Crop growth rate	0.1332	0.1016	0.0125	-0.0174	0.2300
Leaf area index	0.1524	0.1088	0.0111	-0.0197	0.2527

Figures under lined represent the direct effects of the factor

Table 4.84: The direct and indirect contributions of yield and growth components of four castor varieties at 16 WAS in 2006, 2007 and 2008 wet seasons.

	Effect through				
Parameter	**Plant Height**	**Number of Branches**	**Crop Growth Rate**	**Leaf Area Index**	**Total Correlation**
Plant height	0.4416	0.3324	-0.1106	0.1305	0.7940
Number of branches	0.3890	0.3773	-0.1058	0.1130	0.7736
Crop growth rate	0.1173	0.0959	-0.4163	0.2945	0.0915
Leaf area index	0.1305	0.0966	-0.2777	0.4416	0.3911

Figures under lined represent the direct effects of the factor

Table 4.85: Percent contribution of some selected growth components to seed yield of four castor varieties and their residual effect at 16 WAS at samaru, 2006, 2007,2008 and combined wet seasons.

Yield and growth components	% Contribution			
Individual Percent contribution $(P_1)^2$	**2006**	**2007**	**2008**	**Combined**
Combined				
Plant height	64.92	2.03	31.24	19.50
Number of branches	0.53	20.27	16.08	14.23
Crop growth rate	2.64	1.48	0.02	17.33
Leaf area index	0.02	31.13	0.04	19.50
Combined Percent contribution (2PiPjrij)				
Plant height and number of branches	10.53	10.66	41.02	29.36
Plant height and CGR	-8.30	-0.84	0.33	-9.77
Plant height and LAI	-0.66	4.43	-0.60	11.53
Number of branches and CGR	-0.66	-2.53	0.26	-7.98
Number of branches and LAI	-0.05	11.12	-0.43	8.53
CGR and LAI	0.35	-3.30	-0.04	-24.52
Residual	30.68	25.54	12.09	22.29
Total	100	100	100	100

shown by CGR in 2006, 2007 and the combined analysis were all negative (-0.1625, -0.1216 and 0.4163) respectively.

The least combined contribution of two growth parameters to seed yield was from number of branches and LAI in 2006 (-0.0492) plant height and CGR in 2007 (-0.8367), CGR and LAI in 2008 (-0.0436) and number of branches and CGR when the three years data were combined (-7.9843). The percent contribution that could otherwise cannot be explained were 30.7%, 25.5%, 12.1% and 22.3% for 2006, 2007, 2008 and the combined respectively.

4.5 Path Coefficient Analysis and Per cent Contribution of Yield and Yield Components to Seed Yield of Four Castor Varieties.

The direct and indirect effects of some yield components on seed yield of castor in 2006, 2007, 2008 and the combined wet seasons are presented in Tables 4.86 to 4.89.

The results indicated that out of the total correlations of 0.7243, 0.7340, 0.8401 and 0.7929 in 2006, 2007, 2008 wet seasons and the combined respectively, the direct effect of oil content effects on seed yield were all positive and highest 0.7521 in 2006, 0.7778 in 2007, 0.8357 in 2008 and 0.8031 in the combined analysis. The next higher direct effect was exhibited by number of racemes/plant in 2006, raceme length/plant in 2007, 2008 and the combined analysis. The least total correlation was exhibited by number of capsules per raceme in 2006 (0.0633), raceme length/plant in 2007 (0.0053), number of racemes/plant in 2008 (0.1338) and capsule weight of plant in the combined analysis (0.1276).

Table 4.86: The direct and indirect contributions of some yield and yield components of four castor varieties at 16 WAS in 2006 wet season

Parameter	Oil content	Capsule weight of plant	Number of capsules/raceme	Number of racemes/plant	Raceme length/plant	Total correlation
Oil content	0.7521	-0.0143	-0.0386	0.0188	0.0062	0.7243
Capsule weight/plant	0.1976	-0.0546	-0.0921	0.0439	0.0134	0.1083
Number of capsules / raceme	0.1792	-0.0311	-0.1618	0.0612	0.0157	0.0633
Number of racemes/plant	0.2080	-0.0353	-0.1455	0.0680	0.0165	0.1118
Raceme length/plant	0.2247	-0.0352	-0.1219	0.0538	0.0208	0.1422

Figures under lined represent the direct effects of the factor

Table 4.87: The direct and indirect contributions of some yield and yield components of four castor varieties at 16 WAS in 2007 wet season

Figures under lined represent the direct effects of the factor

Parameter	Oil content	Capsule weight of plant	Number of capsules/raceme	Number of racemes/plant	Raceme length/plant	Total correlation
Oil content	0.7778	-0.0068	-0.0175	-0.0394	0.0199	0.7340
Capsule weight/plant	0.1573	-0.0337	-0.0635	-0.1420	0.1147	0.0329
Number of capsule/ raceme	0.1328	-0.0209	-0.1026	-0.1793	0.1857	0.0158
Number of racemes/plant	0.1556	-0.0243	-0.0934	-0.1969	0.1826	0.0235
Raceme length/plant	0.0735	-0.0183	-0.0903	-0.1704	0.2109	0.0053

Table 4.88: The direct and indirect contributions of some yield and yield components of four castor varieties at 16 WAS in 2008 wet season

Figures under lined represent the direct effects of the factor

Parameter	Oil content	Capsule weight of plant	Number of capsule/ raceme	Number of racemes/plant	Raceme length/plant	Total correlation
Oil content	0.8357	-0.0156	-0.0063	0.0028	0.0235	0.8401
Capsule weight /plant	0.2017	-0.0645	-0.0210	0.0112	0.0471	0.1745
Number of capsule/raceme	0.1452	-0.0373	-0.0363	0.0142	0.0513	0.1371
Number of racemes/plant	0.1427	-0.0445	-0.0317	0.0163	0.0511	0.1338
Raceme length/plant	0.2798	-0.0432	-0.0265	0.0118	0.0703	0.2922

Table 4.89: The direct and indirect contributions of some yield and yield components of four castor varieties at 16 WAS in 2006, 2007 and 2008 wet seasons

Parameter	Oil content	Capsule weight of plant	Number of capsule/raceme	Number of racemes/plant	Raceme length/plant	Total correlation
Oil content	0.8031	-0.0200	-0.0140	0.0085	0.0152	0.7929
Capsule weight/ plant	0.1954	-0.0822	-0.0376	0.0248	0.0272	0.1276
Number of capsule/raceme	0.1766	-0.0486	-0.0637	0.0325	0.0348	0.1317
Number of racemes/plant	0.1895	-0.0560	-0.0569	0.0364	0.0353	0.1484
Raceme length/plant	0.1921	-0.0352	-0.0349	0.0202	0.0635	0.2058

Figures under lined represent the direct effects of the factor.

The least but negative direct effect was observed with number of capsules per raceme in 2006 (-0.1618), number of racemes/plant in 2007(-0.1969), capsule weight of plant in 2008 (-0.0645) and the combined analysis.

Direct effect exhibited by capsule weight of plant, number of capsules per raceme were all negative in all the three years and the combined. In addition, the direct effect of number of racemes/plant in 2007 was also negative. It was observed that some indirect effects on yield via other yield components were negative; these include the effects of capsule weight of plant and number of capsules per raceme via all the other yield components in all the three years and the combined analysis. Also, it was recorded in 2007 that the indirect effect number of racemes/plant via all the other yield components were negative.

The individual and combined per cent contribution of individual yield components as quantified in terms of percentage in 2006, 2007, 2008 and the combined analysis are presented in Table 4.90. The result indicated that the highest individual contribution towards yield came from oil contents of seeds 56.57% in 2006, 60.45% in 2007, 65.83% in 2008 and 64.50% when the result was combined. The second most important contributor to seed yield was with number of capsules per raceme (2.62%) in 2006, raceme length per plant (4.45%) in 2007 and (0.49%) in 2008 and capsule weight per plant in the combined analysis (0.68%). There was also a variation on the least direct percent contribution made by the yield components in the period under review. In 2006, the least individual contribution was recorded for raceme length/plant (0.04%), capsule weight of plant (0.11%) in 2007 and for number of

racemes/plant (0.03%) in 2008 and raceme length/plant in the combined analysis.

When the combined contributions of any two yield parameters to castor seed yield were examined, it was found that there was a variation in the highest contribution of the yield components in the three years. In 2006, the combined contribution of oil content and number of raceme/plant (2.83%) was highest while in 2007, number of capsules per raceme and number of racemes/plant was the highest (3.68%).

However, in 2008 and the combined analysis, oil content and raceme length/plant had the highest combined contribution to seed yield of castor of 3.93% and 2.44% respectively. The next higher combined contribution was observed with capsule weight per plant and number of capsule per raceme in 2006 (1.01%). This same effect was observed with oil content and raceme length/plant (3.10%) in 2007 and oil content and number of racemes/plant in 2008 (0.47%) and the combined analysis and (1.38%).

In all the three years and the combined analysis, the combined contributions of oil content and capsule weight per plant, oil content and number of capsule per raceme, capsule weight and raceme length/plant and also number of capsule per raceme and racemes length/plant were all negative. Similarly, in 2006, 2008 and the combined analysis, capsule weight and number of racemes/plant and also number of capsule per raceme and number of racemes/plant combined together contributed negatively to seed yield just as in

Table 4.90: Percent contributions of some selected yield and yield components to seed yield of four castor varieties and their residual effect at 16 WAS at samaru, 2006. 2007, 2008 and combined wet seasons

Yield and Yield Components	% Contribution			
Individual Percent Contribution $(P_1)^2$	**2006**	**2007**	**2008**	**Combined**
Oil content of seeds	56.57	60.49	69.83	64.50
Capsule weight / plant	0.30	0.11	0.42	0.68
Number of capsules / raceme	2.62	1.05	0.13	0.41
Number of racemes / plant	0.46	3.88	0.03	0.13
Raceme length / plant	0.04	4.45	0.49	0.40
Combined Percent Contribution (2PiPjrij)				
Oil Content and capsule weight of plant	-2.16	-1.06	-2.60	-3.21
Oil content and number of capsules/raceme	-5.80	-2.72	-1.05	-2.25
Oil content and number of racemes/plant	2.83	-6.13	0.47	1.38
Oil content and raceme length/plant	0.94	3.10	3.93	2.44
Capsule weight of plant and number of capsules/raceme	1.01	0.43	0.27	0.62
Capsule weight and number of racemes/plant	-0.48	0.96	-0.15	0.41
Capsule weight and raceme length/plant	-0.15	-0.77	-0.61	0.45
Number of capsules/raceme and number of racemes/plant	-1.98	3.68	-0.10	0.41
Number of capsule/raceme and raceme length/plant	-0.51	-3.81	0.37	0.44
Number of racemes/plant and raceme length/plant	0.22	-7.19	0.17	0.26
Residual	46.08	43.53	29.15	36.36
Total	100	100	100	100

2007 where oil content and number of racemes/plant had a negative contribution to seed yield of castor.

The residual effect in 2006, 2007and 2008 was 46.08%, 43.53% and 29.15% respectively representing 53,92%, 56.47% and 70.85% of the variability that could be accounted for in 2006, 2007 and 2008 respectively.

4.6 Regression Analysis

When the regression analysis of different N and P rates against the seed and oil yields of four different castor varieties was carried out (Figures 1,2,3 and 4), it was observed that a linear increase in yield resulted with each increase in N and P rates.

4.6.1 Effect of N rates on yield of four castor varieties

When the regression analysis of different N rates against castor seed yield was carried out in the three years and the combined analysis using ANOVA (Figure. 1) a linear response was obtained giving the following equations:

$Y = 152.6296 + 0.5245\ x$ (2006)

$Y = 150.5139 + 0.7873\ x$ (2007)

$Y = 157.4306 + 0.9664\ x$ (2008)

$Y = 158.5200 + 0.7600\ x$ (combined)

Where Y refers to the expected yield at a given N fertilizer rate x.

4.6.2 Effect of P rates on seed yield of four castor varieties

When the regression analysis of different P rates against castor seed yield was carried out in the three years and the combined wet seasons (Figure 2) a linear response was obtained with the following equations:

Y = 170.1944 + 2.1956 x (2006)

Y = 181.6111 + 2.4797 x (2007)

Y = 182.4167 + 4.2614 x (2008)

Y = 178.0741 + 2.9789 x (combined)

Where Y refers to the expected seed yield at a given fertilizer P rates x.

4.6.3 Effect of N rates on seed oil content of four castor varieties

Analyzing the regression effect of different N rates on yield of castor seed oil content (%) in the three years and the combined wet seasons (Figure 3), it was observed that the linear response emanate from the following equations:

Y = 41.8120 + 0.0306 x (2006)

Y = 42.0060 + 0.0395 x (2007)

Y = 42.1569 + 0.0478 x (2008)

Y = 41.9917 + 0.0393 x (combined)

Where Y refers to the expected yield at a given fertilizer N rate x.

Computing the result at the different N rates, the following yields were obtained:

4.6.4 Effect of P on seed oil content of four castor varieties

When the regression analysis of different P rates against castor seed oil content (%) was carried out in the three years and the combined wet seasons (Figure 4), the following equations were arrived at:

Y = 42.5472 + 0.1449 x (2006)

Y = 42.8889 + 0.2346 x (2007)

$Y = 43.2528 + 0.2462\ x$ (2008)

$Y = 42.8963 + 0.2086\ x$ (combined)

Where Y refers to the expected yield at a given fertilizer P rate x.

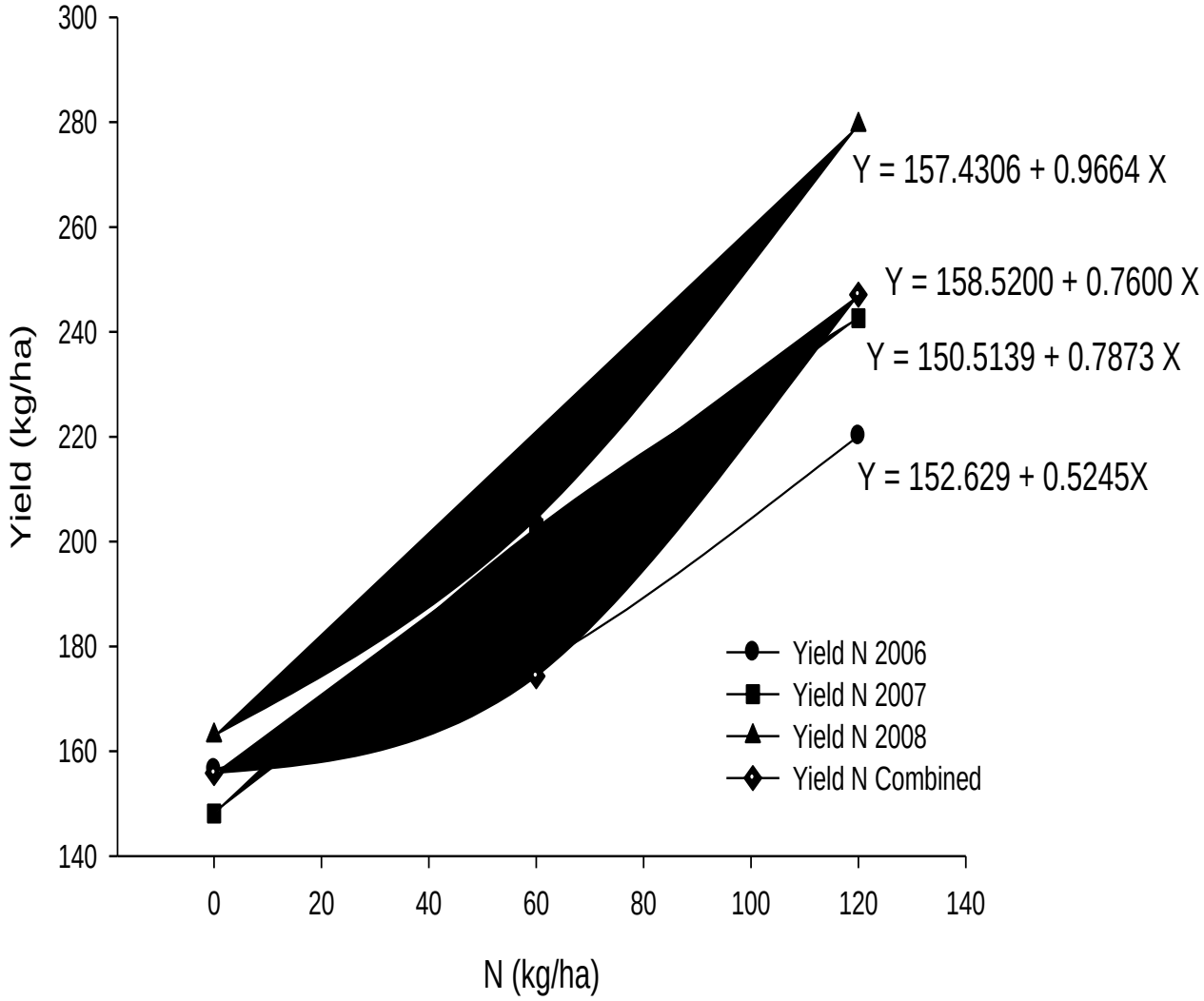


Fig.1: Regression between seed yield and N in 2006, 2007,2008 and Combined

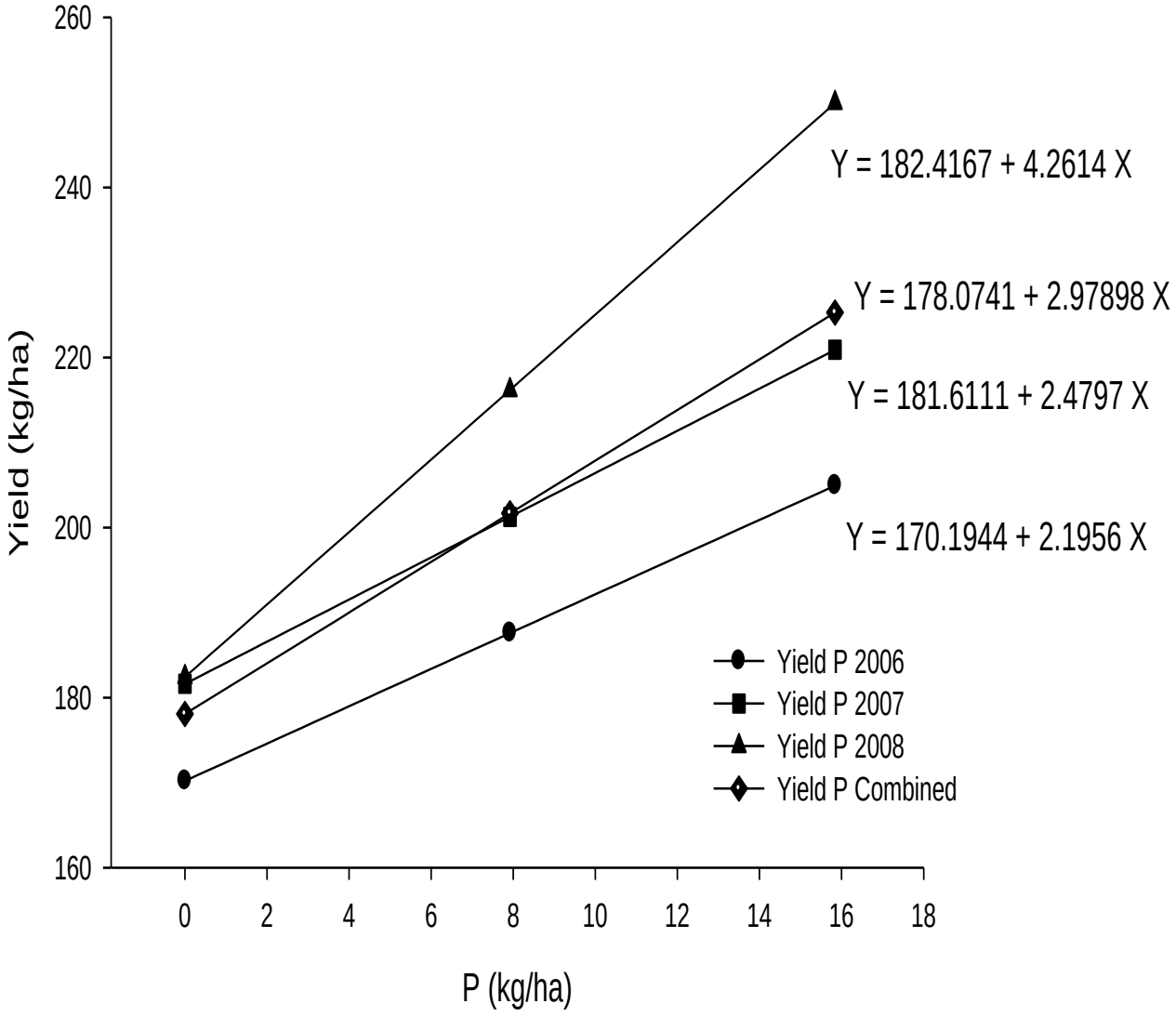


Fig. 2: Regression between seed yield and P in 2006, 2007, 2008 and Combined

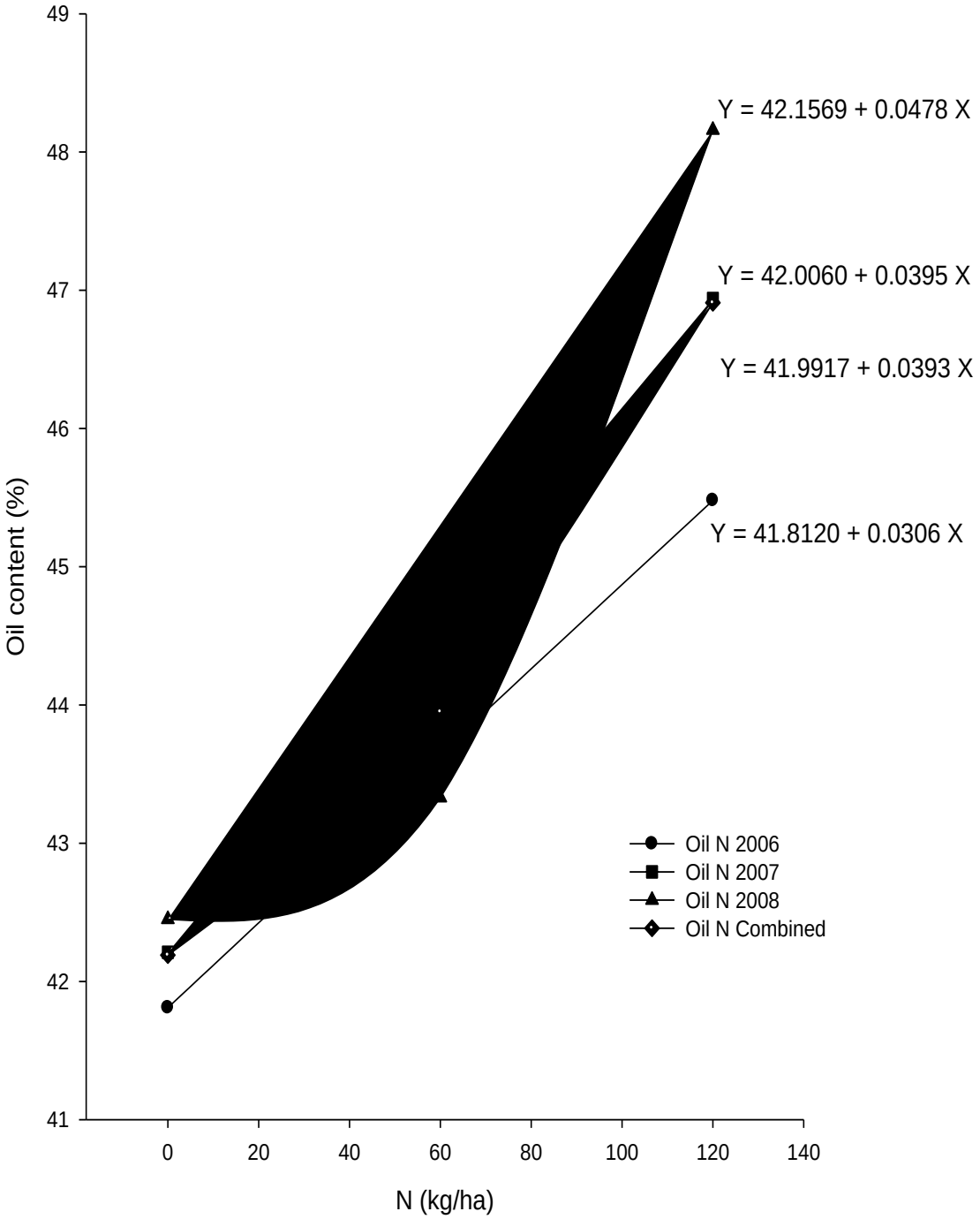


Fig. 3: Regression between seed oil content and N in 2006, 2007, 2008 and combined

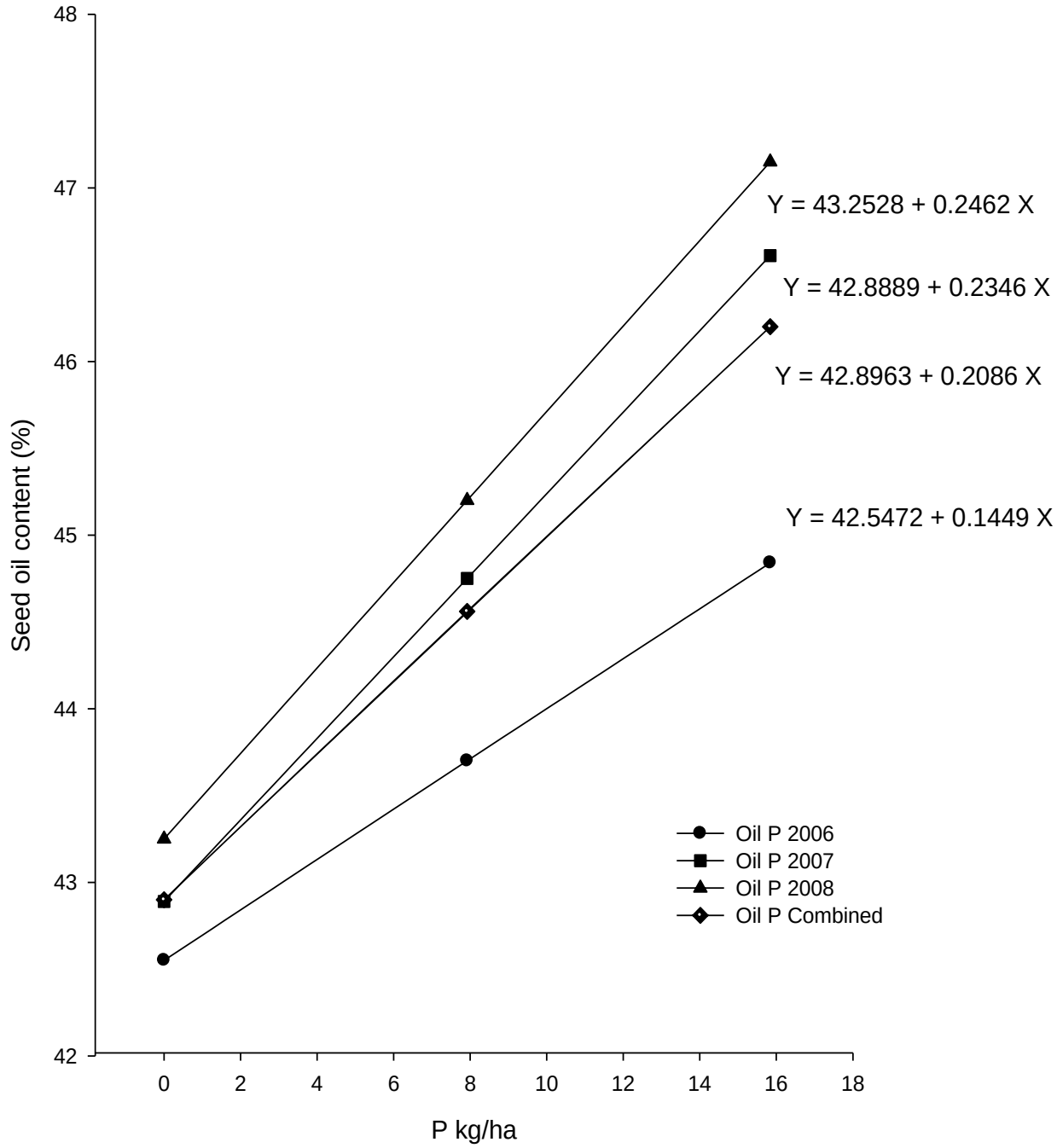


Fig. 4: Regression between seed oil content and P in 2006, 2007, 2008 and Combined

CHAPTER FIVE

5.0 DISCUSSION

5.1 Effect of Season

Studies on the response of Castor beans to seasonal variation amongst growth, seed oil content and yield parameters evaluated in response to environmental factors brought out the fact that the variation in the performance of the four different varieties of castor could be related to the seasonal variation recorded each year during the experimental trial (Appendices i – iii). The amount and pattern of distribution of rainfall at ten-day-interval variation in combination with the variation in temperature, pH and the physical characteristics of soil at the different experimental site of this experiment led to drought of varying intensities and duration during the growing seasons. The resultant effect of these variations which might have occurred during any of the phonological stages of growth is changes in growth patterns and yield. Agro-ecological conditions, according to Manga (2007) could exert an influence on oil content of seed, growth and yield components of castor.

Seasonal effect on growth and yield of castor as affected by N, P and variety was apparently statistically significant. This could probably be due to the fact that the rainfall amount and distribution varied in the three years with rainfall in 2007 season particularly poorly distributed and its sudden and early, cessassion. Although Castor is known to be drought tolerant as reported by Rana *et al.* (2005), the early cessations of rainfall in 2007 did not significantly affect the performance of the crop in comparison with more favorable 2006 and 2008 seasons (Appendices i – iii). However, reduction in values of growth and yield parameters in 2006 and 2007 as observed, must probably have been

caused by early cessation of rainfall and its poor distribution resulting in moisture stress period in late September and October of these two years. It was observed that this situation was not helped by the application of the highest N and P rates in the two years. This corroborates the findings of Falconer (1981) who reported that environmental conditions can cause variability, not only of some traits but also on interrelationships between them. Similarly, Richard (2004) identified moisture stress and temperature as major environmental factors affecting growth and development of castor. Bangarth (1989) reaffirmed that castor yield increases with increase in moisture content of the soil. Oplinger *et al.* (1990) reported that in cases where the supply of N and P to castor is high particularly during the critical stages of castor growth, the poor growth under such condition is as a result of slow response to water shortage probably due to luxuriant canopy development resulting in significantly larger plants with high LAI and above ground biomass and thus increased transpirational demand for water consequently leading to poor performance of the crop. Similarly, Tropilab (2006) found that reduction in photosynthesis under a gradually imposed water stress in castor is highly correlated with low yield. This indicated that possibly with the revival of more favourable weather conditions that led to increased moisture level during 2008 rainy season must have been adequate during the critical growth stages of castor to have given the observed growth and yield. Similarly, the higher LAI observed in 2008 also has promoted higher percentage of light interception which in turn must have supported higher dry matter production obtained in the results. It was possible that the lesser soil moisture content in September and October of 2006 and 2007 must have had a strong negative effect of castor plant photosynthetic performance and consequently this

manifested in poor growth and yield. However, a glance through the rankings of the above mentioned parameters indicated a non significant differences across seasons (Tables 4.22, 4.27 and 4.37). The non significant differences between especially dry matter, seed and oil content prevailed in spite of more than 14 day difference in sowing between 2006 and 2007/2008.

Tropilab (2006) reported that condition of adverse moisture deficit during castor growth period could have negative influence on the development of growth and yield related components and yield of castor such as plant height, number of leaves and branches, total dry matter weight, leaf area, number of racemes, oil content and yield of castor. This strongly suggested that varying or increasing N and P levels under water stress condition particularly during critical developmental stages does not favour the growth and yield of castor. Apart from this, this difference might also have occurred due to variation in sowing dates and stand counts at establishment (3 WAS) and at maturity 16 WAS. Amongst the various critical stages of growth as far as environmental limitation to yield especially rainfall is concerned in castor, is the period between 30-60 days after sowing. Adverse weather conditions during this stage limits yield while favourable conditions increases it (Saletenko 1977, Bangerth 1989 and Lowell *et al.* 2000) This critical period might have coincided with the total rainfall volume experienced in the month of August where 222mm, 298.6mm and 352.6mm of rainfall in 2006, 2007 and 2008 respectively were recorded. (Appendices i – iii). These rainfall torrents experienced in 2006 and 2007 ordinarily as reported by Tropilab (2006) could have been adequate for the growth and yield of castor, therefore differences in growth and yield could have been caused by this variation in rainfall in the three years of this trail.

However, in contrast to this finding De Mooy *et al.* (2002) are of the view that castor is often killed by heavy rainfall and poor soil texture. Abimiku *et al.* (2010) found that high relative humidity during flower formation in castor caused poor performance castor in respect of number of capsules/plant, while Anon (2002) reported also that, with adequate temperature, castor can be raised on the poorest soils with only about 300 – 573mm of rainfall.

The growth components of castor measured over the growing periods showed considerable upward trend and appeared to be increasing over the years (All tables of growth parameters). This trend could also be associated with high favourable minimum temperatures that prevailed during the latter part of the seasons which probably might have positively influenced the vegetative growth and yield increases of the crop. It could be inferred from the results of this study that the best yield obtained with the highest minimum temperature and better light interception that stemmed from high LAI, which could have led to increased efficiency in the use of photo synthetically active radiation in dry matter production was obtained in 2008 compared with the previous years.

To that effect, Hardin (1974) reported that generally, the growth and development of castor is slowed down in response to low temperature even if moisture is not limiting. In an affirmation of this fact, Nnadi *et al.* (1981) and Moshkin (1986) opined that castor being a tropical crop responds positively to the high temperatures experienced around September and October across the seasons. This period coincided with the latter part of the wet season that is important in photorespiration, increased metabolism and better sink filling. In addition it was also observed that each year, flowering coincided within

the month of September. The higher mean temperature experienced in 2008 might have favoured better flowering regime due to increase in photosynthetic activity and faster seed setting to maturity that was necessary for higher yield. Also, as the least number of days to 50% flowering was recorded in 2008, this indicated that more favourable circumstances must have prevailed for castor flowers to emerge early during that period. This is in consonance with the reports of Tropilab (2006) who asserted that the optimum and minimum temperatures of 30^{o} C and 22^{o} C, respectively are favourable for castor seed setting to maturity in order to achieve higher yield. Similarly, Horton *et al.* (2006) explained that castor grows best where temperatures are rather high throughout the season, but seed may fail to set if it is above 38^{o} C for an extended period. Also Nnadi *et al.* (1981) indicated that days to 50% flowering in castor differ significantly with season. Similarly, Domingo and Crooks (1999) reported that high temperatures decreases post–an thesis growth, accelerates senescence reactions and causes premature loss of chlorophyll. Consequently crops that experience high post an thesis temperatures set very rapidly. This has manifested in 2008 where it was observed that plants matured earlier than the previous years resulting in faster seed setting in 2008. This has significantly improved the yield in that year. This idea is in conformity with that of Anon (2000) who concluded that treatments which resulted in early vegetative growth and flowering are more likely to yield better than when initial growth is limited. On the other hand, Hardin (1974) argued that castor yields better when temperatures are higher than 40^{o} C. Similarly, the yield variation observed from the work of Horton *et al.* (2006) further revealed that beside moisture, higher thermal regime is also required to

achieve generally higher yields in castor. This may be due to its heat loving nature and higher heat requirement during its growing period (Tropilab, 2006).

To a large extent, the nature and composition of soil characteristics used each year for the trial proved to have gone a long way in determining the adaptability of castor which could have had a beneficial or detrimental effects on resource utilization, thus affecting the filling of sink and consequently yield. The lower values recorded for growth and yield attributes of 2006 and 2007 lend credence to part of this assertion when compared with results of 2008. This observation could be attributed to the fine clayed texture of the soil which caused water-logging condition in the experimental plots of 2006 making the applied P probably unavailable to the crop through fixation resulting in yield reduction. According to Gobin *et al.* (2001) the best soils for castor cultivation are rich well drained sandy loams. This they added, is because a water-logged soil condition can deprive the crop of the availability of P no matter the quantity applied. However, a contrary view to this was reported by Anon (2001) who asserted that castor can thrive under varied conditions of soil and climate. It can be grown on any type of soil and from sea level to an elevation of 1524 – 2133 m above sea level, but it cannot withstand frost. The evidence of a high level of clay particles at the plot used for the trial in 2006 and 2007 (appendices iv) could also have given the soil higher PH, lower P value and more clay than is required for proper growth of castor. The soil composition of experimental site of 2008 is comparatively more favourable for castor growth and yield than in the preceeding years (Appendix iv), consequently, higher growth value and yield were recorded. Poor drainage of soil militate against good growth and yield in the two seasons of 2006 and 2007. In consonance with this, Anon (2006) reported on the

importance of soil aeration to growth and yield of castor. Similarly Brigham and Spears (1961) explained that castor is killed by heavy rainfall, water logging and poor aeration. They further reported that castor requires well drained sandy loams that are deep. Thus apart from aeration, poor drainage might have affected nutrient uptake in castor in 2006 and 2007. The result of this study had shown that growth and yield parameters were higher in 2008. This was followed by those observed in 2007 while in most cases the least was recorded in 2006. The differences in these characters in the three years could be associated with the acidic nature of the experimental site in 2008 and higher N, P and K content of the soil (Appendix iv). Several explanations for this are advanced. Oplinger *et al.* (1990) explained that growth, oil content and yield attributes of castor can be markedly influenced by soil pH, available soil N, P and K. Gobin *et al.* (2001) hold the view that castor does not tolerate soil alkalinity but prefers slightly acidic soil. These favorable features are all dominant at the experimental site of 2008 thereby rendering it possible for growth and yield attributes to be better. Similarly, Goebel (1980) stated that castor can tolerate a pH of between 4.5–7.3. In addition Grimmer *et al.* (1999) affirmed that castor can only tolerate soils that are neither alkaline nor saline.

5.2 Varietal Effect

Results of this study indicated that the varieties of castor differ in their potential productivity as they exhibited significant differences in their growth and yield characters. From the results, it is obvious that there were significant differences between the big-

seeded (Ex-Brazil 1 and Ex-India 2) and the small- seeded varieties (Ex-Brazil 2 and Ex-India 1). Similarly, a significant difference also exists amongst the big-seeded. Ex-Brazil 1 in most cases exhibited the higher growth and yield parameters than all the other varieties used in this study. Pathak and Verma (1965) and Singh (1968) supported this finding when they reported that castor growth and seed yield being a combination of complex characters are usually determined by several inter–related components. Notably amongst these components are the genetic make–up of the variety and the effect of the environment. Similarly, castor crop varieties according to Salatenko (1975) differ genetically in their potential productivity and their relative responses to management practices.

Ex-Brazil 1 and Ex-India 2 are morphologically similar seed wise and can be classified as tall with erect bunch and more profuse branches. Their seeds being the biggest and heaviest according to these findings also have the advantage of height to first raceme, higher number of capsules, larger capsule diameter and higher Sulphur and Sodium contents in their leaves. In spite of these similarities, an interesting fact that emerged from this study was that all the growth and yield parameters and also seed yield per hectare in all the three years of this study and the combined. Seed oil content especially in 2006 and the combined were higher with Ex-Brazil 1 than Ex-India 2. In fact, Ex-India 2 was observed to have the lowest yield and yield attributes amongst all four castor varieties used. It could be possible that its assimilates were used in the production of growth parameters instead of increasing the seed yield. It also appears that due to their growth habits and the potential ability of the big seeded cultivars to produce better yield and growth parameter as exhibited by Ex-Brazil 1, the big seed

varieties could also have more of the ability to utilize intercepted radiation and hence greater partitioning of their dry matter into reproductive yield. The inability of Ex-India 2 to make use of this advantageous qualities proved that the Indian big castor varieties is the least adapted variety amongst the four varieties used in this trial. To this effect, so many supportive reports are advanced. Evans (2003) reported that the big seeded varieties of castor usually exhibit a more profuse branching with taller plants than the small seeded that are in most cases referred to as the semi dwarf varieties. He therefore concluded that larger seed yield is usually obtained from the big seeded varieties given adequate fertilizer and moisture requirements.

Savan and Giri (1987) also reported that there are variations in the genetic composition of the small and the big-seeded varieties of castor. This leads to various degrees of differences exhibited in their growth, seed oil contents and yield characters. Anon (1992) explained that the taller castor varieties produce higher number of racemes per plant and consequently more seeds per capsule. This contributes significantly to their seed yield per hectare than the small seeded varieties. Conversely, Kauroubas *et al.* (1999) are of the view that the shorter varieties of castor are more fertilizer and moisture responsive due to their stiff straw that resists tendencies to lodging at especially high N-levels which leads to succulence. Tall cultivars are more predisposed to lodging at high N rates (Khadke and Riazuddin, 2000).

The fact that the Ex-Brazil 1 proved to be more superior than Ex-Indian 2 in seed oil contents, growth, and yield parameters especially in 2006 and the combined analysis does not seems to be surprising because flowering which occurred earlier in them is strongly related to capsule formation. The earlier formed flowers are more successful at

early and latter seed setting. In relation to this, Smith *et al.* (1981) stated that generally the earlier the seeds are formed in castor, the more likely they are to reach maturity early. This has a positive influence on seed yield and other related characters. This explains the better adaptability of Ex-Brazil 1 to Samaru environment where they were established.

It was also observed from the result of this study that the yield per hectare obtained by Ex-Brazil 2 which is a small seeded variety was higher than Ex-Brazil 1 despite the potential advantageous characteristics exhibited by the big – seeded varieties. This could be attributed to the fact that Ex-Brazil 2 had the longest days to 50% flowering flowering meaning that it must have utilized longer photosynthetic days to produce better yield. This view was earlier shared by Souza *et al*. (1976), who postulated that a higher python mass and yield was associated with longer duration genotypes. De mooy *et al.* (2000) also supported this fact when they reported that earliness pays penalty in yield reduction due to short duration of yield formation. Results of this study also revealed that Ex-Brazil 2 produced the highest number of capsules/raceme. This could be that its genetic make up is most suited to the environmental and fertilizer doses it receives during the trial to convert assimilates produced to more capsules/raceme. In line with this findings, Vranceanu and Stoenascu (1964) and Singh and Sherma (1985) reported that castor varieties differ in their ability to partition dry matter into capsules and seeds in response to environmental factors and fertilizer doses. They added that the big seeded varieties are usually late maturing and thus more time is allocated to the partitioning of assimilates to racemes, capsules and seeds.

The results of this work also indicated that the Brazilian varieties had in most cases higher values of growth and yield parameters with Ex-Brazil 2 closely following Ex-Brazil 1. In addition to this, the ability to flower early and mature late by these Brazilian varieties as per the result of this study, was an added advantage to increased seed oil content, growth and yield characters. This influence on seed yield and other related characters revealed the adaptability of the Brazilian varieties to Nigerian environment. Also the ability to maintain the highest leaf magnesium content, longer raceme length and highest yield demonstrates another aspect of their adaptability to the environment they were established. In agreement with this fact is the report of Mathuvel *et al.* (1987) who explained that high seed yield in castor is associated with the crop's adaptability to its environment.

There were also some qualitative aspects of the small seeded varieties (Ex-Brazil 2 and Ex-India 1) over the big seeded ones in that the highest number of capsules/raceme particularly in 2007, leaf calcium, nitrogen, phosphorus, potassium content and more importantly the highest percentage of oil in their seeds. In accordance with this, Ananda *et al.* (1993) reported that castor seed oil content is associated with seed size with larger seeds producing less oil than the small seeded varieties. Similarly Madhukia and Modhwadia (1993) explained that oil content of castor and most important elements are higher in concentration in the small seeded varieties than in the big seeded. Khadke *et al.* (2000) also reaffirmed that modern semi dwarf small seeded castor cultivars are associated with higher partitioning efficiency resulting in more oil deposit in their seeds. Lowell *et al.* (2002) also explained that oil content for small seeded castor varieties are always higher than that of the big seeded especially when

given adequate fertilization. However, in trial using the two different seed size varieties by Shaw (2002), it was found that high seed yield in castor is not associated with more oil content. He went further to prove that an average yield of 3.08 and 2.83 tonnes per hectare contained 35.14 and 48.3% oil for the big and small seeded castor varieties respectively. Similarly Khadke and Riazuddin (2000) reported in their work with 1123 that is a big seeded variety and UC 53 that is a small seeded, an average seed yield of 3359 and 2246 kg ha^{-1} yield with oil content of 30 and 51.2% respectively was obtained.

5.3 Effects of N

The role of N in castor crop physiology is evident in the result of this work in that generally N enhanced growth and yield of castor as each increase in the quantity of N led to an increase in seed oil content, growth and yield parameters. Madhukia and Modhwadia (1993) explained that N is an important component of many important structural, genetic and metabolic components in plant cells. It is a major part of chlorophyII, amino acids and many of the biochemical reactions on which life is based. Therefore availability of N must have led to increase in growth, seed oil content and yield of castor in the three experimental years. In a similar manner, the result of this work is related to that of Abubakar *et al.* (2010) who pointed out that application of N to castor resulted in significantly taller plants, higher number of capsules/raceme, racemes/plant and seed yield.

5.4 Effects of P

Results of this study indicated that P is necessary for proper growth and yield of castor in that in plots not supplied with P, there were evidences of poor growth and yield across the varieties of castor. To this effect, De Mooy *et al.* (2002) reported that P is

responsible for the transfer of energy from one reaction to another within cells. Adequate P availability in castor stimulates early plant development and hastens maturity of the crop (Lowell *et al.,* 2002).

5.5 Interactions

5.5.1 Nitrogen and phosphorus interaction

Compared with the control, all other rates of N and P progressively and significantly increased both growth and yield characters of castor with the exception of leaf nutrient content. Data generated in this study are indicative of castor's response not only to the presence or absence of N and P fertilizer but also reflected the differential responses of castor to low and high N and P levels in the three seasons. This is because there was a direct proportionate increase in both vegetative and reproductive yield components of castor with each increase in N and P rates. The positive influence of N and P interaction on the performance of castor confirmed the essentialities of both nutrients in promoting growth and root development resulting in increased uptake of both nutrients from the soil culminating on yield. To that effect, Hardin (1974) and Doorenbos and Kassam (1979) explained the complementary effect of N and P on castor in which N tends to promote vigorous growth and increase the photosynthetic capacity of the crop in terms of increased LAI, while P encouraged seeds and root development thereby increasing yield as a result of increased solubility and uptake of P in the presence of N. it was also reported by Weiss (1982 and 1983) that the application of N along with P in castor produced the highest absorbed shoot K concentration than when neither N nor P was applied. This he explained may be attributed to the vigorous vegetative growth and root development resulting in the

increased uptake of K. Another supportive report made by Salih (1981) and Armstrong (1982) explained that the complementary role played between N and P on vegetative and reproductive growth could be attributed to the ability of N and P fertilizer to promote foliage growth, increased meristematic and physiological activities in castor thereby resulting in the synthesis of more photo–assimilates which are used in producing higher yield. Similarly, Weiss (1983) reported that the growth and yield of castor is maximally achieved with increase in doses of N and P when these two are combined but not when applied separately. They reaffirmed that high levels of N are not recommended without the application of P as they perform a sort of complementary functions.

5.5.2 Nitrogen and variety interaction

With all the four varieties, there was a significant interaction between N and variety for growth attributes such as plant height, number of leaves in 2006 and 2008, plant dry weight, CGR, days to 50% flowering and with all the yield attributes and oil content of castors across the period of this investigation. This indicated a positive correlation between the various N rates and the different varieties of castor used in enhancing growth and yield components. This confirms the result obtained by Rao and Vantateswalu (1994) who reported that castor varieties differ in their response to N fertilizer rates, duration to maturity and the size and colour of seeds. Jana *et al.* (1990) on the other hand, are of the view that the higher the doses of N applied to any variety of castor, the better the performance in terms of growth and yield. However, a contrasting view as reported by Bangerth (1989) explained that the shorter varieties of castor are more fertilizer and moisture responsive.

5.5.3 Interaction of P and varieties

The varieties used in this experiment exhibited a significant interaction with the different levels of P. This was shown clearly only with a few of the growth parameters such as plant height in 2006, days to 50% flowering and with yield parameters such as capsule weight per plant, seed yield per hectare and oil content of seeds. Kulkarni (1968) and Birgham (1970a) reported that the advantages of matching different castor varieties with required doses of P are for high yield potential, elimination of capsule shattering and uniform hull strength and thickness.

5.6 Correlation Analysis

The strong and positive correlation between castor seed yield and growth characters such as plant height, number of leaves per plant, number of branches per plant, plant dry weight, CGR, days to 50% flowering and LAI indicate the importance of good vegetative development in producing high yield and also the interdependency within and between these characters. Similarly, the positive and highly significant correlation between yield and yield characters such as seed oil content, diameter of capsules, number of seeds per capsules, number of capsules per raceme and raceme length per plant suggests that these characters were most critical determinants of seed yield in castor and thus constitute important characters that should be considered by breeders for improvement. This finding is in conformity with those of Brigham (1993) who noted a highly significant positive correlation between seed yield of castor and vegetative dry matter, seed oil content and some yield components in castor. The other growth and yield characters assessed made their highest indirect contributions through plant and seed yield per hectare. This further emphasized their importance to seed yield of castor.

5.7 Path Coefficient Analysis

The path coefficient analysis revealed that among the growth characters selected, plant height and LAI made the highest positive contribution of 19.50% each while seed oil content made the highest positive contribution of 64.50% amongst the various yield component selected. This suggests that these characters were most critical determinants of castor seed yield and thus constitute important characters that should be considered by breeders when breeding for high yielding varieties in castor. The other growth characters assessed made their highest direct contribution through plant height in all the period of this study except in 2007 where LAI made the highest indirect contribution amongst the growth components. Seed oil content made the highest direct contribution when the yield characters were assessed.

5.8 Leaf Tissue Analysis

Plant leaf tissue analysis was used to determine the relative quantities of mineral elements in the leaves of the four castor varieties used in this study. Pandey and Sinha (2006) have reported that analysis of a plant revealed the presence of a large number of mineral elements of which the amount and number of elements in plants differ with location and medium in which the plants grow. In this study, no significant difference was observed in the leaf concentration of N, P, K, Ca, Mg, Na and S. However, it was observed from result of this study that the small seeded castor varieties produced higher Ca, N, P and K content but in most cases it was highest in Ex-Brazil 2. The Brazilian varieties had more of Mg content than their Indian counterparts. However, the

big seeded are better accumulators of S and Na, with the Brazilian variety having a higher concentration. This indicated the variation of mineral elements in the different seed size of the varieties. This trait is attributed to differences in the genetic composition of the four varieties of castor. In conformity with this finding, Russel (2000) observed that the concentrations of cations in most plant tissues such as actively functioning leaves are also characteristics of the crop. In experiment with the big and the small seeded castor varieties, Domingo (2001) observed that increasing the N and P rates from 0 to 280mg P pot^{-1} had no significant effect on leaf N and P content of UC 53 castor variety.

5.9 Regression Analysis

The regression analysis conducted on N and P rates against seed and oil yields of the castor varieties in 2006, 2007, 2008 and the combined means revealed a linear increase in yields of oil and seeds with each increase in N and P rates. This shows that fertilizer rates used in this study were not the optimal for maximum obtainable yields thus giving room for further research studies on other higher N and P rates on castor.

CHAPTER SIX

SUMMARY AND CONCLUSION

Field trials were conducted during the rainy seasons of 2006 – 2008 on the research farm of the Institute for Agricultural Research, Ahmadu Bello University, Samaru-Zaria ($11^{0}11^{1}$ N Latitude; 07^{0} 38'E longitude and 686m above sea level) to study the effects of different N and P rates on growth, yield, seed oil content, growth and yield parameters of four castor land races (Brazilian and Indian). The treatments consisted of three levels of N (0, 60 and 120 kg/ha) supplied in the form of urea, three levels of P (0, 7.92 and 15.84 kg/ha) supplied in the form of single super phosphate and four castor bean land races (Ex-Brazil – 1, Ex-Brazil – 2, Ex-India – 1 and Ex-India – 2).

The treatments were laid out in a split plot design with N and P levels combined and allocated to main plots while the four varieties were assigned to subplots. The treatments were replicated three times.

The results revealed that compared with the control, the higher rates of N and P progressively and significantly increased both growth and yield characters and seed oil content with the exception of leaf nutrient contents.

This positive influence of N and P interaction on the performance of castor confirmed the essentialities of both nutrients in promoting growth, yield and oil content production.

The big-seeded castor varieties (Ex-Brazil-1 and Ex-Indian-2) had the biggest and heaviest seeds, longer height to first raceme, longer capsule diameter and highest S and Na in their leaves. The small seed-castor varieties had higher numbers of capsules/raceme particularly in 2007, highest number of days to 50% first flowering, highest plant count at harvest, highest leaf Ca, N P, K and seed oil content with the Brazilian small seeded varieties having the highest oil content value. The Brazilian varieties were better adapted to Nigerian environment as they produced castor plants with earlier formed flowers that have late maturity periods, highest leaf Mg, longer raceme length and highest yield but with big seed variety producing more of each of these parameters, indicating that higher yield in castor in not necessarily associated with oil content. There was a significant interaction between N and variety or plant height, number of leaves in 2006 and 2008, plant dry weight, CGR, days to 50% first flowering and with all the yield components and seed oil content . The interaction between P and varieties was significant on plant height in 2006, days to 50% first flowering, capsule weight per plant, seed yield/hectare and seed oil content. Correlation

studies indicated a strong and positive correlation between seed yield and plans height, number of leaven/plant, number of branches/plant, plant dry weight, CGR, days to 50% first flowering and LAI. It also showed a positive and highly significant correlation between seed yield and seed oil content, diameter of the capsule, number of seeds per capsules, number of capsules/raceme, diameter of capsule, and raceme length. It suggested that these parameters constitute important characters that should be considered by breeders for yield improvement. Path coefficient analysis results revealed that plant height and LAI and also seed oil content made the highest positive contributions to growth and yield, respectively. Seed oil content made the highest direct contribution when the yield characters were assessed.

The per cent contribution of some growth and yield components indicated that seed oil content consistently made the highest individual contribution to seed yield in all the three years and the combined analysis. The combination of oil content and number of racemes/plant in 2006, oil content and raceme length/plant in 2007, 2008 and in the combined analysis were observed to have made the highest contribution to seed yield.

Regression analysis revealed a linear increase in yields of oil and seeds with each increase in N and P rates indicating that the fertilizer rates used were not the optimal for maximum obtainable yields, thus giving room for further studies on other higher N and P rates.

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Appendix I: Meteorological Data Showing Monthly Rainfall, Temperature and Relative Humidity during 2006 Wet Season.

Month	Rainfall (mm) At 10 days Interval	Temperature ^{0}C			Mean Relative Humidity (%)
		Maximum	Minimum	Mean	
May	30.6 40.9 50.8	34.0	22.0	28.00	73.0
June	35.0 43.2 47.9	32.0	21.0	26.5	72.2
JULY	101.3 119.3 111.0	30.8	20.8	41.2	78.3
August	87.6 79.3 55.1	30.0	20.0	25.0	82.0
September	101.4 90.2 83.4	30.8	19.4	25.1	80.2
October	12.8 11.8 10.2	32.3	19.9	26.1	66.4
November	0	31.2	13.5	22.4	22.0
December	0	30.4	12.5	21.5	16.6
Total	1112				

Source: IAR Samaru Meteorological Unit

Appendix II: Meteorological Data Showing Monthly Rainfall, Temperature and Relative Humidity during 2007 Wet Season.

Month	Rainfall (mm) At 10 days Interval	Temperature ^{0}C			Mean Relative Humidity (%)
		Maximum	Minimum	Mean	
May	43.4 50.1 56.8	35.1	22.5	28.8	68.1
June	56.8 74.9 76.8	31.2	20.4	41.4	74.0
July	60.7 80.2 87.7	30.1	20.8	25.50	81.4
August	80.0 96.7 121.9	30.0	20.1	25.0	79.6
September	19.8 8.7 3.4	31.5	20.1	25.3	79.6
October	4.2 3.0 1.1	34.5	18.1	26.3	59.4
November	0	NA	NA	NA	NA
December	0	NA	NA	NA	NA
Total	926.3				

NA = Not Available
Source: IAR Samaru Meteorological Unit

Appendix III: Meteorological Data Showing Monthly Rainfall, Temperature and Relative Humidity during 2008 Wet Season.

Month	Rainfall (mm) At 10 days Interval	Temperature ^{0}C			Mean Relative Humidity (%)
		Maximum	Minimum	Mean	
May	30.2 31.6 33.4	34.9	21.8	28.4	62.9
June	35.8 36.0 39.9	33.1	20.8	27.0	72.3
July	53.4 64.6 83.3	30.9	20.0	25.5	79.5
August	129.8 122.2 100.6	29.7	19.4	24.6	81.9
September	89.3 72.4 55.8	31.2	25.4	28.3	77.0
October	32.2 30.0 26.8	33.4	18.2	25.8	21.1
November	0	NA	NA	NA	NA
December	0	NA	NA	NA	NA
Total	1066.4				

NA = Not Available
Source: IAR Samaru Meteorological Unit

Appendix IV: Physico – chemical characteristics of soil taken from a depth of 30cm at the experimental site.

Soil Properties	**2006**	**2007**	**2008**
Physical properties			
% sand	56	59	63
% silt	30	29	26
% clay	15	13	9
Textural class	clay loam	clay loam	sandy loam
Chemical properties			
pH in H_2O	7.1	7.5	5.8
pH in 0.1m $CaCl_2$	5.4	5.7	4.8
% organic carbon	0.43	0.22	0.41
Available P (C mol/kg^{-1})	4.011	2.56	9.44
% Total nitrogen	0.68	0.035	0.88
Exchangeable cations (C mo/kg^{-1})			
K	0.33	0.38	0.49
Mg	0.33	0.33	0.33
Ca	1.00	1.80	1.0
Na	0.18	0.17	1.18
CEC	1.80	2.81	1.68

Exchangeable acidity H^+ and Al	0.80	0.10	0.80

Source:- Soil samples as analyzed at Soil Science Department, IAR/ABU, Zaria.

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