

Urea Fertilization: Effects on growth, nutrient uptake and root development of the biodiesel plant, castor bean (*Ricinus communis L.*)

Abstract

An indoor pot culture experiment was conducted in the growth chamber during the period of vegetative growth to evaluate the influence of inorganic nitrogen fertilizer in the form of urea on nutrient uptake, growth and root development of castor bean plant. The Nitrogen Fertilizer treatments imposed in the experiment were: Control (N0), no nitrogen and others at the rate and 60lb N/acre (N1), 90lb N/acre (N2) and 120lb N/acre (N3) respectively. Effect of higher nitrogen concentration indicated considerable increases in castor growth including vegetative growth and the plant components biomass. Elevated nitrogen fertilizer increased height and other morphological and physiological parameters (Leaf and petiole length, internodal distance, root numbers) including the root, shoot dry wt, root/ shoot ratio, nitrogen and crude protein content in plants. Among the plant components, shoot, root dry weight and root shoot ratio had the greatest decrease under N deficiency, while root/shoot carbon ratio increased under N deficiency.

No statistical different was observed with treatments in shoot and root N% and shoot C% in plants although root carbon content was significantly higher with lowest nitrogen level compared to elevated levels. Significant increases of carbon content in plants at N0 showed some tendency of this crop to adjust with lower nitrogen levels Also no statistical difference was observed in root and shoot N ratio, while the root and shoot carbon ratio was found significant at N0 compared to other treatments. However the concentration of carbon and nitrogen were found higher in shoot than root in all applied treatments. After harvesting the residual nitrogen effect in soil was also found significant with elevated nitrogen level compared with other treatments and control.

Key words: Castor bean, Growth, Urea, Nitrogen uptake, Root/Shoot Ratio

Introduction

Castor bean (*Ricinus communis L.*) is a non food, drought resistant and an important oilseed bioenergy crop, especially for the production of biodiesel. This energy crop gaining attention for producing fuel in developed as well as in developing countries. Castor finds a place of prestige in the cropping systems of dry-land agriculture because of its deep root system, drought hardiness, and quick growth. It is widely cultivated throughout the world for fuel use as well as it has number of uses for domestic, and industrial purposes. It belongs to the family Euphorbiaceae and is also one of the medicinally important oil seed crop (Kumari et al., 2008). Castor oil, one of the oldest commercial products, was used in lamps by the Egyptians more than 4,000 years ago and seeds have been found in their ancient tombs (Al Tamimi and Hegazi, 2008, Weiss 1971).

Although castor commonly referred to as a "bean," it is not a legume and the plant has also been called the "castor oil plant." The plant may grow upto a height of 6 to 15 feet and can live for many years. The seeds contain 5.1-5.6% moisture, 12–16% protein, 46 to 60% oil and are a rich source of phosphorus. The oil consists of Oleic, ricinoleic, linoleic, stearic acids (Shafiee et al., 2009). So as an oil bearing biomass feedstock, it can ensure an alternative source of energy and reduce our dependency on fossil fuel. Like other biodiesel plant, *Jatropha*, this plant can grow anywhere including soil considered infertile for food production (Nahar et al 2011).

Castor plant is generally produced from seed and the time from planting to emergence was found to vary in between 7 – 23 days, depending on soil temperature (Nahar 2013; Weiss, 1971, 2000; Cheema et al, 2010., Kittock and Williams 1967a) and as well as regeneration by tissue culture, to receive disease free, large number of plants for commercial cultivation. Regeneration by tissue culture technique would also be a feasible alternative for improving the quality and to develop an efficient protocol for propagation of castor oil plant (Nahar and Borna 2012, Kafagi 2007., Raven et al., 1999., Riazuddin 2012., Novero and Jamiri 2012).

As a medicinally important plant, it is also purgative popular for the treatment or prevention of many ailments. The leaves have been used for treatment of rheumatic pains and as antibacterial and anti-inflammatory (Kumari et al., 2008, Bonjean, 2002; Luseba et al., 2007, Akande et al 2011). The oil also prescribed for infestation of intestinal worms. Infusion of the leaves was used as a remedy for rash, itch and eye inflammation. The decoction of leaves also used for skin diseases, diarrhea, kidney, urinary bladder infections (Boulos, 1983) and the oil is used in mainstream medicine as a way to deliver chemotherapy drugs to cancerous tumors (Fjällskog et al., 1994; Fetrow and Avila, 1999).

Production of castor plants has increased since the middle of the twentieth century (Rajarathinam and Parmar 2001). Although, India, China and Brazil are the major world producers of castor oil, the plants are also grown commercially in many other countries, including the United States (New Mexico, Texas and the Midwestern United States), Philippines and Thailand. EU, China, Philippines, Paraguay, Brazil and United States sub tropical regimes (FAO 2009). Production of castor is needed in the United States to supply castor oil for the hundreds of products using this versatile chemurgical raw material. Forty to forty five thousand tons of castor oil and derivatives are imported each year to supply the entire needs of domestic industries. The United States is the largest importer and consumer of castor oil in the world. The oil is classed as a strategic material critical to the United States national defense by the Agricultural Materials Act P.L. 98-284 passed by Congress in 1984 (Roetheli et al. 1991). Castor bean yield in the US, however, dependent on the latitude and management practices (Kittock and Williams, 1967, 1970;); maximum yield reported was 2690 kg ha⁻¹ in southern Nebraska under irrigated conditions (Oplinger et al., 1990). In a recent planting date and location study in the US south-central region showed that castor bean mean yields were greatest at Memphis, TN, the northern most location (maximum, 1954 kg ha⁻¹) and lowest at Poplarville, MS, the southernmost location (Baldwin and Cossar, 2009).

Castor bean is successfully cultivated in tropical and sub tropical regimes to reduce the dependency of fossil fuel. The plant grows as an annual in cold and arid areas. But in the tropics and sub tropics, the plant is a perennial (Cherry, 2009). The oil contains a very high percentage of

hydroxy fatty acid (Glaser et al., 1993) known as ricinoleic acid. Ricinoleic acid can be treated by dehydration. This dehydrated castor oil is in demand for paints and varnishes because of its non-yellowing quality. The oil has a great promise in the field of biodiesel production or in addition the oil can be used in biodiesel studies (Ogunniya 2006, Anonymous, 2009c). Besides being used as a source of biodiesel the oil is also used in polishes, ointments, waxes, printing inks, cosmetic, hair dressings and disinfectants. The oil is also used for the synthesis of soaps, linoleum, printer's ink, nylon, enamels and electrical insulations, dyeing and finishing of fabrics and leather, preservation of leather and production of Rilsan-polyamide nylon-type fiber (Ombrello, 2009; Deore and Johnson, 2008, Derksen et al., 1995, Caupin, 1997, Ogunniya 2006; Osava, 2003). The oil has also been used as a lubricant in all parts of machinery and for internal combustion engines in airplanes and in making of explosives (Duke, 1986; Onwuliri and Anekew, 2001; Alam et al., 2010). It is also used as an illuminant with a steady flame and burning much longer than any other vegetable oil.

Castor with a global average yield with about 40–60% oil is a more suitable and viable biodiesel crop than the traditional oil seed crops such as soybean and sunflower with 25.5% of oil and with 18% oil, respectively (FAO, 2006; Pimentel and Patzek, 2005). In recent years, the oil is largely used in the specialty chemical industry worldwide, and the growth of its consumption is limited by insufficient and unreliable feedstock supply rather than by the industry demand (Severino et al., 2012a). Therefore, castor bean crop can become a cash crop in modern agriculture, in particular, for non-food uses including bioenergy purposes (Vignolo and Naughton, 1991; Murphy, 1993). Although increased castor production in the world can be obtained with the use of varieties and hybrids with higher genetic potential and an improved crop management. The transition from a low-input/low-yield to a high yielding crop will require a deeper understanding of castor plant growth and development. This knowledge is the key for the breeding of high yielding varieties adapted to each growing environment and for the optimization of crop management in order to express the maximum yielding potential of the crop (Severino and Auld, 2013). In addition, compared to soybean and sunflower, little work has been done so far in castor bean, and with additional agronomic production and plant breeding studies (Auld et al., 2001; Baldwin and Cossar, 2009), the crop may have more potential than presently realized.

For agronomic production, Nitrogen is most important macronutrient that all plants need because this fertilizer is an integral component of amino nucleic acids, proteins, nucleotides, chlorophyll, chromosomes, genes, ribosome and is also a constituent of all enzymes. This wide range of different nitrogen containing plant compounds explains the important role of nitrogen for plant growth (Blumenthal et al., 2008). In plants, nitrogen present in the chloroplasts, which are the molecules within plants, perform photosynthesis for making food. If plants do not have enough nitrogen, they turn yellow, in part because the chloroplasts are not functioning properly (Narits, 2010). Also, if the soil is deficient in nitrogen, Alternaria leaf spot (disease) is more severe in nitrogen-starved plants (Dufour et al., 2003). The most important factor in fertility level is the supply of nitrogen in the soil (Kalimantan, 2011).

Different abiotic stresses cause extensive losses to agricultural production worldwide (Boyer, 1982; Bray et al., 2000). Among those stresses, the availability of nitrogen (N) is the major limiting factors in crop growth, development, and finally economic yield (Glass, 2003; Parry et al., 2005). Farm managers generally apply N on majority of the crops except N-fixing legumes

and the amount and application time dependent on crop growth stage, weather, tillage practice, and on soil N status. The major requirements are for the production of seed (Mengel et al., 2006) and forage (Kingston-Smith et al., 2006). Nitrogen is the most critical element of plant development as the plant growth is affected differently by various N sources (Ryle et al., 1978). The different sources of N using for plant indicated that the growth (fresh or dry weight) is always more in nitrate than various reduced N sources (Lahav et al., 1976).

So, responses of plants to N fertilization are of considerable importance in agriculture. Crop yields have been steadily increased over the last 60 years by a combination of improvements in genetics and management practices including N application (Stewart et al., 2005; FAO, 2006). Although adequate supply of N to crops is fundamental to optimize crop yields, mismanagement of N, such as excessive N application, can result in contamination of groundwater (Jaynes et al., 2001). Applying different nitrogen levels (0, 40, 80 and 120 kg ha⁻¹) indicated highest seed yield, and biological yield under application of 80 kg ha⁻¹, whereas highest seed weight (thousand) was achieved under 120 kg ha⁻¹. The oil percent decreased under increased nitrogen application (Farahani and Aref, 2008). Functional relationships between plant nitrogen (N) and crop growth processes are not available in many crops including castor bean plant (Reddy et al 2010).

The application and effects of different doses of N fertilization on castor bean depend on soil and climatic condition of different countries. 30 kg ha⁻¹ nitrogen are considered as best dose for *R. communis* in Egyptian condition whereas, 50 kg ha⁻¹ and 100 kg ha⁻¹ considered under Belgium and Ankara conditions respectively (Shams et al., 1967, Pohlmeier 2007., Maryan and Dilek 2012). However N frequently limits growth and development of several crop species under field conditions, the precise mechanisms by which the limitation occurs are complex and variable (Reddy et al., 1997a), depending on species, developmental stage and environment. Limited N supply also decreases rates of cell division and cell expansion (Roggatz et al., 1999), photosynthesis, leaf production, tillering (Chapin, 1980; Clarkson and Hanson, 1980; Evans, 1983; Radin and Boyer, 1982; Sinclair and Horie, 1989; Reddy et al., 1997a; Gerik et al., 1998; Zhao et al., 2003, 2005a,b), and yield (Zhao et al., 2007). N deficiency affects more strongly the leaf area development than photosynthesis (Watson, 1952; Wong, 1979; Radin and Boyer, 1982). The effects of low N nutrition on plants as causing lower photosynthetic rates and slower leaf area expansion resulting from lower hydraulic conductivity as altered responses to water stress (Field and Mooney 1986., Gerik et al. 1998, Reddy et al 1997b). So plant species often exhibit substantial variation in rates of nutrient gain and resource use. Developing alternate crops and the utilization of bioenergy crops produced on American farms as a source of renewable fuels are concepts with great relevance to current ecological and economic issues at both national and global scales. Castor bean (*Ricinus communis* L.), as a fast growing C3 plant is now being investigated as a new source for biodiesel and as well as an industrial crop (Baldwin and Cossar, 2009) because of its high oil yield and various potential uses. N requirements, in castor is relatively high compared to other oil seed crops such as soybean, an N-fixing leguminous plant and variable depending on the soil organic matter (Oplinger et al., 1990).

Critical leaf N levels, functional relationships between leaf N and growth and developmental processes and developing rapid and less expensive diagnostic tools for spatial and temporal estimation of plant N status for castor bean crop are needed for producers to manage this crop for

optimum yields under varied growing conditions. Castor bean plant N uptake and nutrient flow (Oplinger et al., 1990; Peuke et al., 1994a,b) and N effects on leaf ontogeny and growth have received some attention now a days (Roggatz et al., 1999).

Nitrogen has been considered as the most critical and is a very essential component for plants growth as plants use nitrogen in the creation of specially proteins and nucleic acids, which are then used for the construction of leaves, other important structures and finally fruits to seeds. The nitrogen can then help the plant produce larger crops because of the increase in the nitrogen available for creating these structures. Urea fertilizer containing 46% of Nitrogen promotes healthy growth by providing essential nitrogen to plants and also allowed an increased N utilization as compared to other fertilizer sources as well as better than other reduced N sources and appeared to be the best source which gave the highest dry matter yield compare to other nitrogen sources are used (Cheema and Abrar 2000., Razieh et al 2012).

The objectives of this present study were to investigate the effects of urea on a biodiesel plant growth, development and physiology, and to derive functional relationships between root, shoot and responses of N in controlled environment including characterize urea uptake and assimilation by castor seedlings by following N metabolites of seedlings with exposure to different levels of N (urea) fertilization regimes and to examine possible interactions between N and carbon transport to shoot and root at various growth stages.

Material and Methods:

A pot experiment was conducted under controlled condition at the Growth Chamber, Department of Crop and Soil sciences, Washington State University during summer season in 2013 to evaluate the effect of different doses of inorganic nitrogen fertilizer in the form of urea on growth, nutrient uptake and root development of castor bean, Zanzabaries variety during the period of vegetative growth and the different parameters were measured weekly till the final harvest.

The experiment was arranged in a Randomized Complete Block Design (RCBD) with 4 treatments and 4 replications. The treatments imposed on the experiment were: Control (N_0), no nitrogen and others at the rate of 120 lb/acre (N_3), 90lb/acre (N_2) and 60lb/acre (N_1) by applying N fertilizer with 391mg/pot (N_3), 293mg/pot (N_2) and 195mg/pot (N_1) respectively. The experiment was carried out by applying pure nitrogen from source of urea (46% N) as chemical fertilizer were maintained for 4 weeks (28 days) in this condition to grow the plants. The soil used in the experiment was the following physical and chemical properties: Sand 46.08 %, silt 46.09 %, clay 7.83 %, Bulk density 1.8, EC 0.39 mmhos/cm, pH 8.0, organic matter 0.75 %, Moisture 3.2%, CEC 10.3 meq/100 g soil and Total N 0.02 %.

Seeds of castor Zanzibaries, were obtained from local seed mass of Oregon,USA. Homogenous seeds were soaked in wet paper towel for 24 hours before sowing and were sown in plastic pot (7inches x 6 inches) containing 6.6 lbs(3 kgs) of Silt loam soil at the growth chamber. The soil

218 was collected from Prosser, Washington State and the collected soil was air dried and sieved to
219 pass a 2 mm mesh screen.

220
221 One seed of castor was sown in each plastic pot and were germinated after 12 days of sowing in
222 the growth room (approximately 14h light/10 h dark) providing photosynthetically active
223 radiation of 80 $\mu\text{mol m}^{-2}\text{s}^{-1}$ with day/night temperature of 75 °F and 57 % relative humidity.
224 The plants were grown under this controlled growth chamber conditions during the vegetative
225 growth for a period of approximately one month (28 days) or four weeks. The plant samples
226 were collected every week to measure the morphological and physiological parameters during
227 the growing period. Finally at the end of the experiment after treatment for 28 days (4 weeks) the
228 castor bean plants were finally uprooted carefully, made free from soil particles and sampled
229 for growth (plant height, leaf and petiole length, intermodal distance, root number), nutrient
230 concentrations in root and shoot and plant biomass were measured. After harvesting the plants
231 were first washed with tap water to remove the soil particles from the root and then with distilled
232 water. Plant parts (roots and shoots) were separated and the fresh weight was determined for
233 each plant. The plants were then dried for 48 hours at 47 degree Celsius to receive the dry wt of
234 samples. The samples were then grind for chemical analysis and used for determination of
235 nitrogen, carbon and crude protein content in plants.

236 Plant heights were measured as the distance between soil surface and the main-stem apex. Leaf
237 and petiole length were estimated non-destructively by measuring the distance from the point of
238 petiole attachment to the leaf tip of the center lobe on all main-stem leaves and intermodal space
239 by measuring distance between internodes. For determination of root number on pot grown roots,
240 soil with intact plants and roots were taken up carefully from the soil depth with a knife. The soil
241 cores were immersed in water overnight in darkness at 5 °C. The roots were then removed
242 carefully using a kitchen sieve.

243 Fresh and dry wt of plants were measured in every week and at the end of the experiment were
244 made after harvesting the plants at 28 DAE. Plant height (cm/plant), shoot dry weight (g/plant),
245 root dry weight (g/plant), and root no (for 3 weeks) were recorded. Total biomass (g/plant) and
246 root:shoot ratio were derived from basic data. After harvesting the data were statistically analyzed
247 using Duncan's multiple range technique (DMRT), to determine the significant differences of the
248 results.

249 So, the aim of the present study was to investigate the effects of fertilizer on this oilseed
250 bioenergy crop, castor bean seedlings at the 6 leaf stage, subjected for 28 days under controlled
251 growth chamber condition, taking in consideration the morphological and physiological quality
252 of the underground and aboveground parts of the plant under different doses of urea.

253

254

255

Results and Discussions:

256 The results were presented in response of different growth, biomass and nutrient concentration
257 parameters to different levels of Nitrogen at vegetative growth for a period of 4 weeks, and their
258 responses to N increasing from 195 to 391 mgs/pot and control. The improvement of each
259 parameter due to increased and reduced N at different growth stages were measured over control
260 level values, and the maximum responsive growth stage to different levels of N was identified.

261 During the vegetative period, the growth, and other parameters were measured weekly as well as
262 plant components biomass from 1st to 4th week (final harvest at 28 DAE). Maximum growth and
263 developmental rates were achieved in 4th week at N3 compare to other treatments and all growth
264 rates declined and were more sensitive at controlled followed by increasing rate of fertilizer
265 application (Fig 1- 2) like N1, N2 and N3 respectively. Although Plant dry weight and root/shoot
266 ratio had the greatest increased under higher nitrogen and lowest under deficiency. Among the
267 plant components plant height, intermodal space addition, leaf and petiole length were higher at
268 N3.

269 Nitrogen in the form of urea influenced the vegetative growth of the plants. The greatest plant
270 height (17.1 cm), dry weight (1.0 g) of shoot, leaf length (6.2cm), petiole length (12.1 cm),
271 intermodal distance (2.5cm), number of roots (22), and root dry wt (0.55gm) were obtained
272 highest with the application of 391gm N/plant treatment. Nitrogen affected the growth, nutrient
273 uptake and root development significantly influenced the vegetative growth of the plant showed
274 that plant height significantly varied with treatments (Fig 3-6). Maximum plant height was
275 recorded at N3 followed by 16.3 cm at N2 and 16.0 cm at N1, whereas the lowest value 14.5cm
276 was recorded at control.

277
278 The results indicated that application of urea in a concentration of 120lbs/acre or 391mgs/pot
279 showed the best effect on root development and other parameters. Functional relationships
280 between leaf Maximum growth and developmental rates were also achieved at this treatment.
281 Among the plant components, plant dry weight and root/shoot ratio had the greatest decrease
282 under N deficiency. Significant difference was not observed among the treatments in any of the
283 parameters like shoot nitrogen and carbon uptake and root Nitrogen uptake, except the root
284 carbon percentage which was highest at N0 and lowest at N3 were measured. However, no
285 significant difference was observed in root/shoot nitrogen ratio under the nitrogen fertilizer
286 treatments and at control condition (Table 1-2).

287 The results indicated that the plant growth and other morphological parameters were improved
288 by applying higher dose of N (Fig 1). Also the root/shoot ratio, nutrient uptake, Crude protein
289 concentration and residual N% in soil increased. The lowest root carbon uptake was observed in
290 plants treated by higher urea. Application of higher dose of urea substantially improved the plant
291 height, leaf and petiole length, intermodal space addition, shoot and root dry weights, and
292 number of roots. While the lowest root no was observed in plants treated by control (Fig 3). This
293 improved growth with higher nitrogen fertilizer in plant is mainly due to nutrient availability in

the fertilizer at N3 and uptake by plants. Adding nitrogen to the soil provides a surplus of food at the plant's disposal that allows it to support more biological processes at an accelerated rate. As a result, the nitrogen allows the plant to grow much faster than it might otherwise without the nitrogen introduced.



Fig 1: Effect of different N doses on plant growth and development: L(N₀-N₃), R(N₃-N₀)



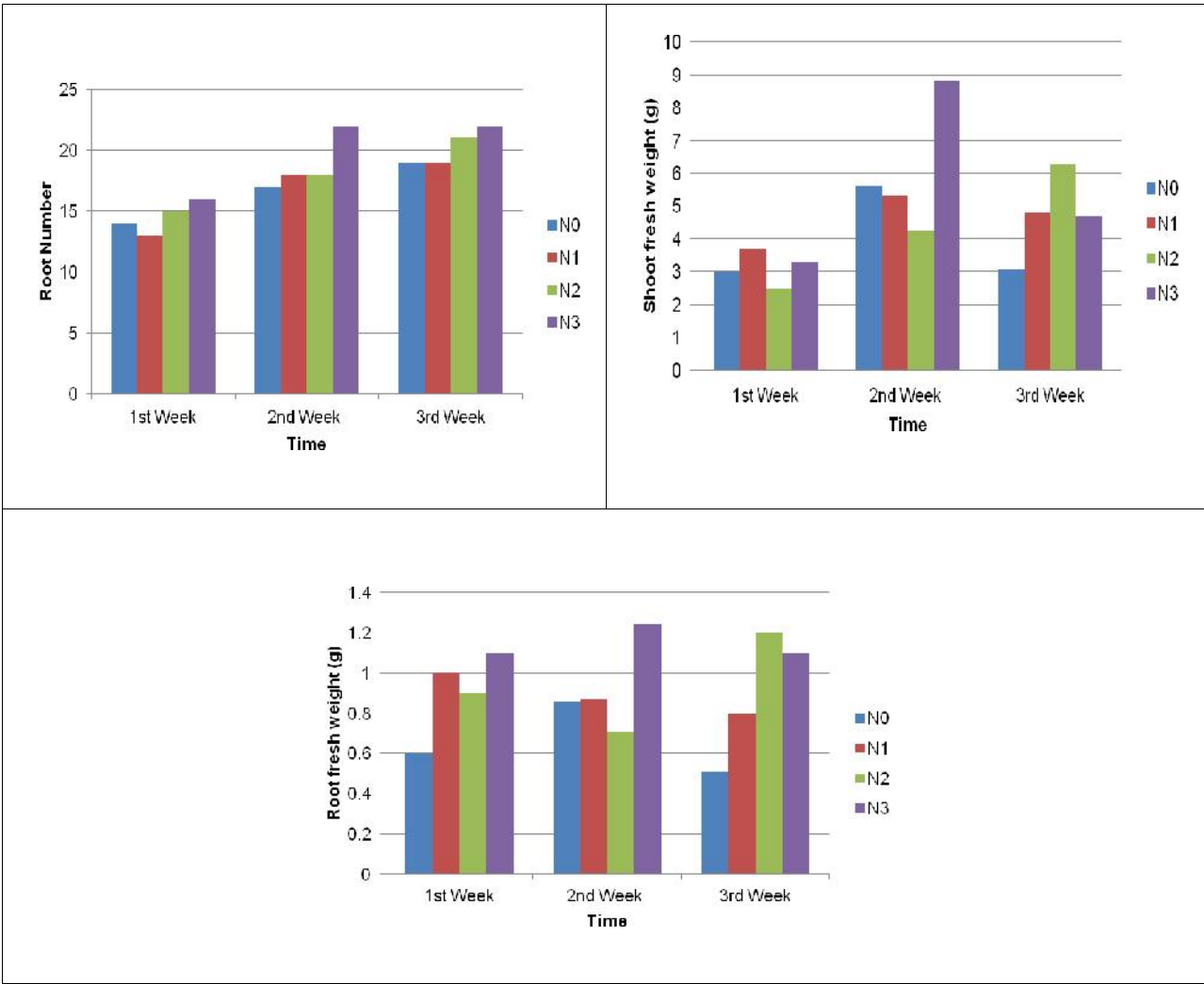
Fig 2: Root development under different rates of Nitrogen: L(N₃- N₀) and R(N₀-N₃)

So, effect of higher concentration of urea indicated considerable increases in castor growth including vegetative growth and the whole plant fresh and dry weight (Fig 3-6). At 28 DAE at harvesting, dry weights of plant components were measured and found shoot and root dry weight had the greatest increase under elevated nitrogen supply and had decrease under N-deficiency. The highest values of nutrient especially nitrogen and crude protein contents in plants were also obtained at N3. However, lower nitrogen applications had no significant effect on most of the investigated plant parameters, except for root/shoot C ratio and uptake of carbon by roots. Effects of different nitrogen doses on some plant physiological characteristics after harvesting are given in table 2.

Root number increased throughout the vegetative growth period, i.e. from 7 to 21 days after emergence and the highest root no was recorded at 21 days and the number under elevated N was higher at all stages when compared with control (Figure 3). Among the elevated N levels, at N3

showed a better response than N₂. At different growth stages the increment in root number varied from 16 to 22 with N₃ from 1st to 3rd week when compared with control and the maximum response was recorded at 3rd week for treatment N₃. So, during the vegetative growth the root no was highest at 21 days after emergence and at elevated nitrogen N₃ treatment followed by N₀ and N₁, however the root and shoot fresh wt was found highest in 2nd week at the same treatment (Fig 3).

Fig 3. Effect of urea on weekly development of root and shoot fresh wt and root numbers



In the last week (4th week) of vegetative growth, finally the plant height was measured and the highest height was observed at N₃ followed by N₂, N₁ and lowest at N₀. Leaf length was also found highest at N₃, same at N₂ and N₁ and lowest at N₀ (control). In case of petiole length, same trend was found, which was highest at N₃ and N₂, followed by same at N₁ and control. Root and shoot fresh wt were higher at N₃ and highest value were obtained in 2nd week compared to 1st and 3rd week. Intermodal distance was also found highest at N₃ followed by N₂, N₁ and N₀,

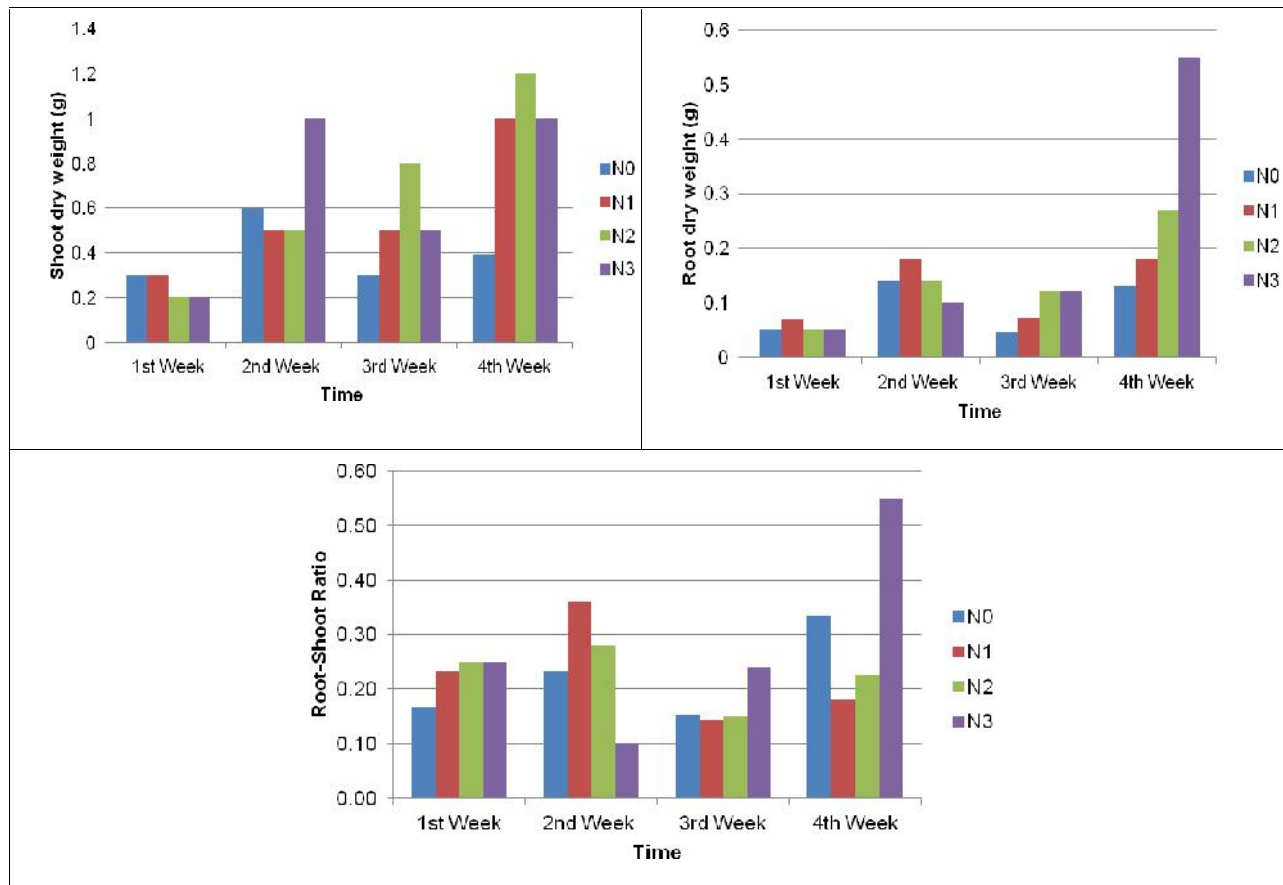
which was lowest compare to other treatments. Shoot dry wt was found higher at N₂ and followed by N₃, N₁ and lowest at N₀, whereas Root dry weight was highest at N₃ and followed by N₂, N₁ and N₀. Crude protein concentration and root shoot ratio were also highest at N₃ treatment compare to others and the Root shoot ratio was also found highest at N₃ treatment followed by N₀, N₂ and N₁ (Fig 6).

It is also evident from the Fig 1, that Root number increased with elevated nitrogen application and with time (weekly) and the highest root no was found in 3rd week followed by 2nd and lowest in 1st week. Although the no of root was found highest in 3rd week with elevated nitrogen level, however the number could not be determined in 4th week, due to the limited space for root development in the pot. Again shoot and root fresh wt were highest at N₃ in second week, compared to 1st and 3rd week. However the shoot N% in first week was higher at N₃ treatment and lowest at N₀, and followed by the sequence (N₃>N₂>N₁>N₀). At N₃ treatment in 4th week, the concentration of nitrogen in root and shoot were increased compared to N₀ treatment but no statistical difference were observed among the treatments. No statistical differences in Carbon value was also observed in shoot among the treatments, so percentage of carbon is statistically same in all treatments, and no differences are observed from N₀ to N₃ treatments whereas in case of root carbon value, opposite picture was found and the highest value was obtained at N₀ and lowest at N₃, and followed a reverse sequence as N₀>N₁>N₂>N₃ (Table 1). The results in table 1 also indicated that the uptake of nitrogen and carbon were higher at shoot than that of root in all the treatments imposed in the experiment.

Also in 3rd week, the shoot N% was highest at N₃ and followed by same at other treatments N₂, N₁ and N₀. Although the root N% was also highest in 3rd week at same treatment, it followed the sequence N₀, N₂ and N₁. Also in final or 4th week shoot N content followed the same sequence as the 3rd week and was found higher at N₃ followed by N₂ and N₁ as same and lowest at N₀. The same trend was found at final stage in root nitrogen conc. as highest value was obtained at N₃, followed the same as shoot Nitrogen uptake. Finally it is observed that at different growth stages of castor in growth chamber from 1st to 4th week (final week) in all treatments showed lower carbon and nitrogen concentration in root compared to shoot N and C concentration. Compare to N% and C%, shoot containing more Nitrogen and Carbon than root in all treatments and every week till the final harvest.

So in the comparison of different N doses, tests showed that higher level of N application (391mg urea/pot) to castor bean plants had more of an effect on the dry weight and other morphological and physiological parameters of the plant as well as soil residual N effect. Although high level of N application do not show any positive effect on root carbon uptake by plants. The nitrogen contents in roots of plant grown in soil containing N₃ was generally lower than the nitrogen contents of stem. However, nitrogen applications had no significant affect on most of the investigated physiological plant parameters, like, root and shoot nitrogen and shoot carbon uptake and root/shoot nitrogen ratio. Effects of different nitrogen doses on some physiological characteristics of castor bean are shown in table 1 and 2.

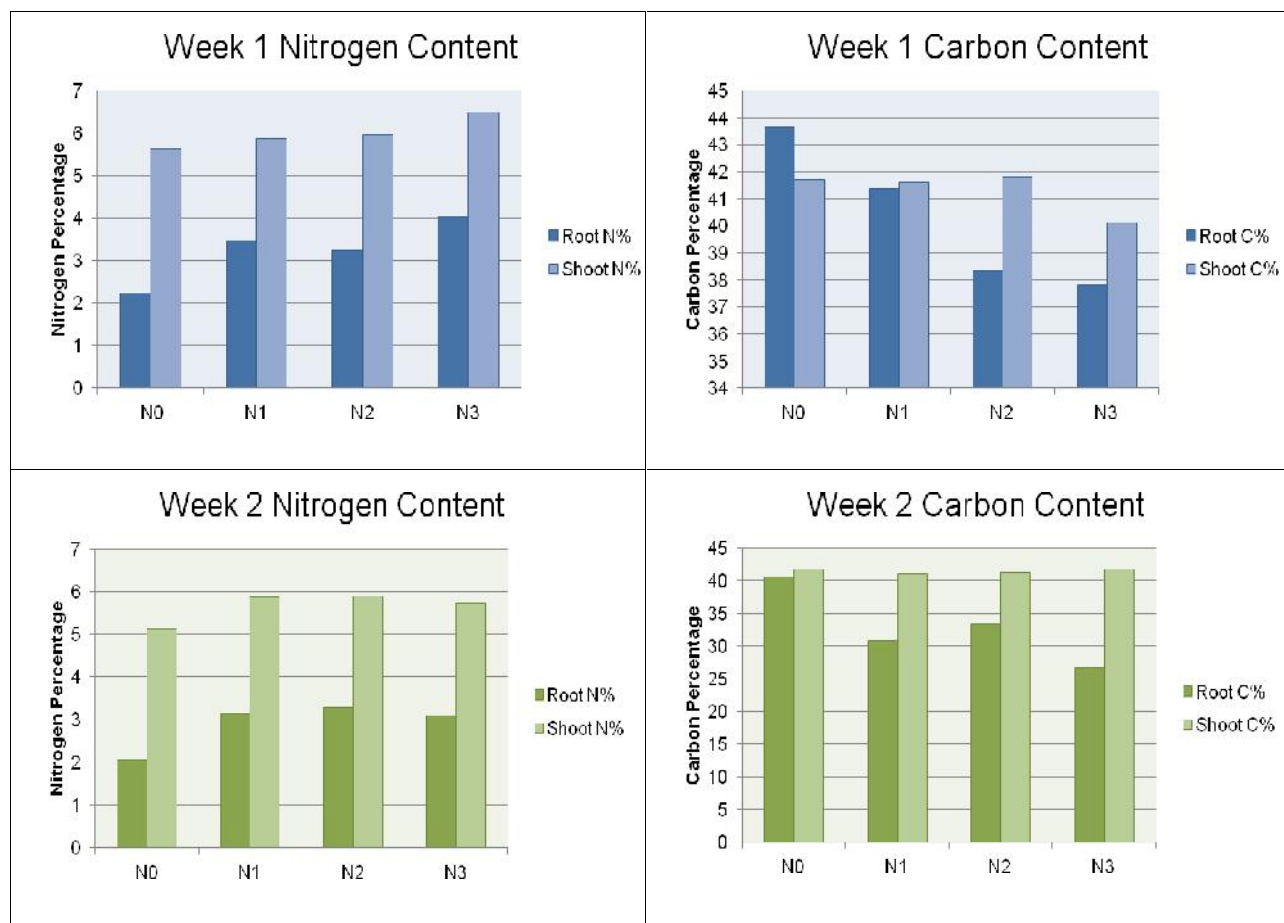
Fig 4. Effects of different doses of Nitrogen on dry wt and root shoot ratio



In this experiment nutrient uptake and growth of aboveground and belowground parts of castor were ascertained in seedlings at various vegetative growth stages until the end of the experiment. Our results indicated that application of urea at the rate of 120lb/acre or 391 mg/pot showed the best effect on castor plant development. Increased shoot and root growth was only at the highest N level applied. No statistical difference was observed between shoot and root N, root carbon uptake and root/shoot N ratio whereas there were statistical differences in root carbon and root/shoot carbon ratio which was highest at control, although the residual N concentration in soil was highest at application of elevated nitrogen levels compared with other treatments and control (N0).

It is therefore evident from the results, that the Castor bean plant showed significant response under elevated Nitrogen levels in terms of growth, biomass and uptake of nutrients when compared with control. Castor responds very well to N nutrition due to its indeterminate growth habit and reduced N resulted in reduced growth and nutrient uptake and root development. In addition, N deficiency decreased plants growth leading to lower biomass accumulation in plants. Partitioning of biomass to roots decreased more than the other plant components especially shoots under N deficiency.

Fig 5. Effect of different doses of urea on nitrogen and carbon uptake by plant at different time intervals.



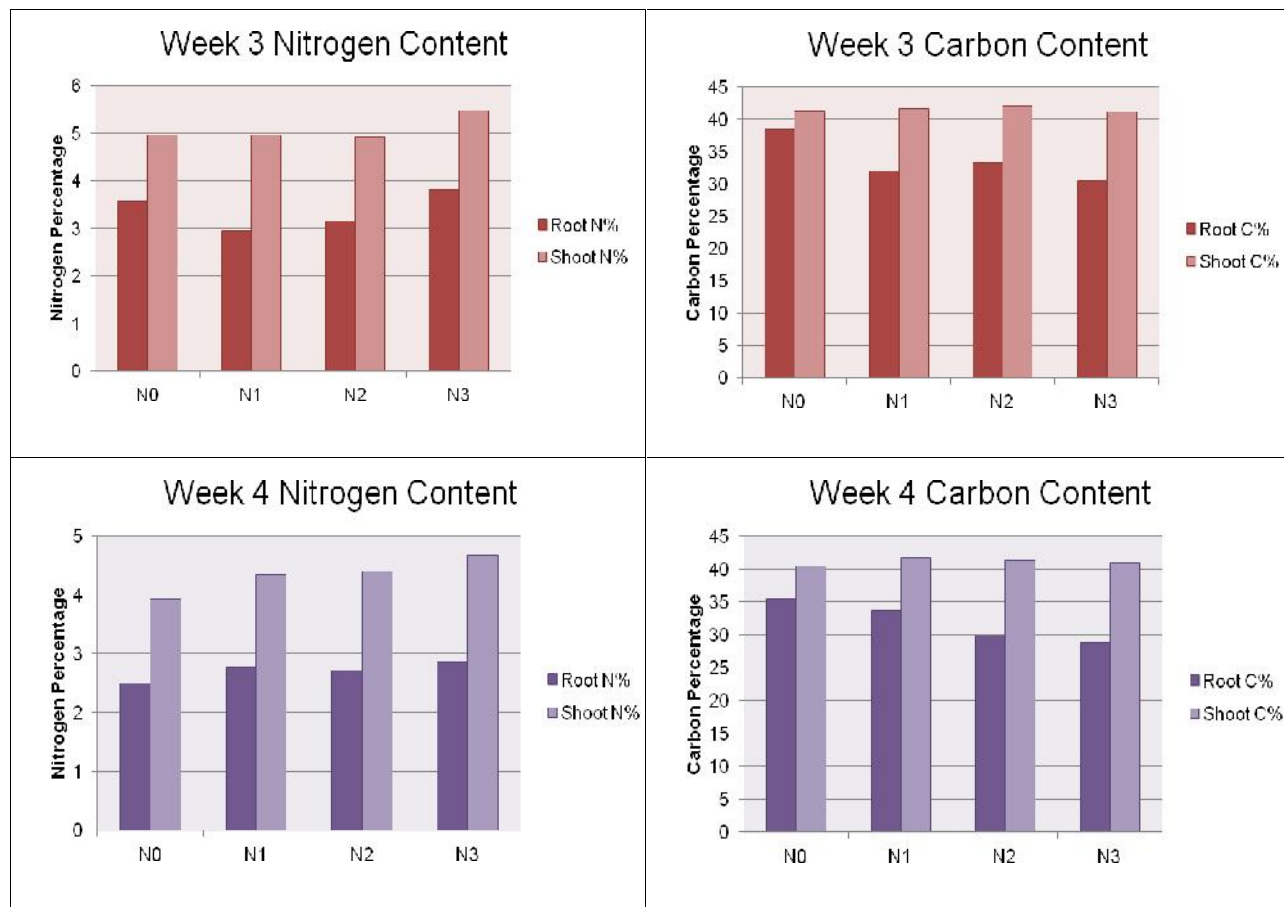
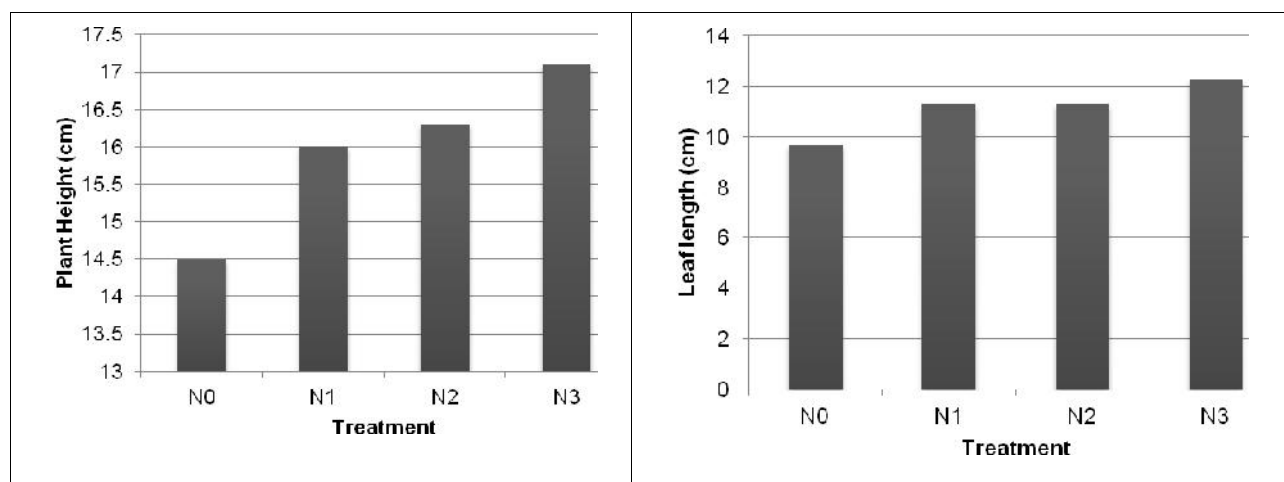
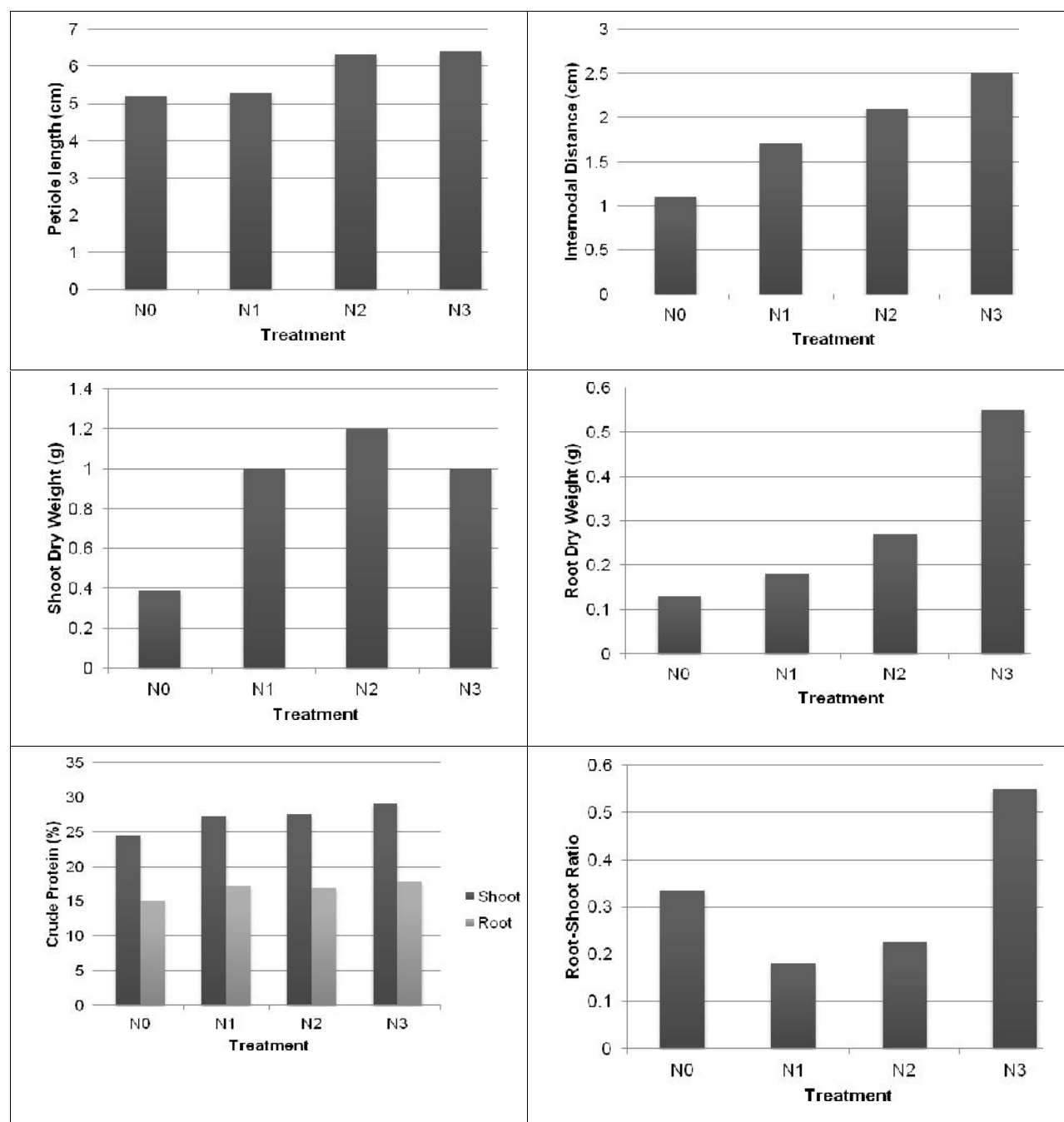


Fig 6.Effect of different doses of urea on growth and other characteristics in plant (4th week)





399 Root dry weight followed the same trend as root number and it increased from 7 to 28 DAE.
 400 Initially, root dry weight increased slowly in the 1st week but from 21 to 28 DAE it showed the
 401 maximum increase (Figure 4). The highest root dry weight was recorded at 28 DAE in N₃
 402 compare to all the treatments.
 403

404 Effect of nitrogen fertilizer on root and shoot, nitrogen and carbon uptake and root/shoot
 405 nitrogen carbon ratio per plant in 5 % probability level was significant. On the other hand, effect
 406 of nitrogen fertilizer treatments on root and shoot nitrogen, root carbon uptake and root /shoot
 407 nitrogen ratio was non significant. Comparison between nitrogen levels show that the highest

plant height, root no, leaf length, root dry weight and root shoot ratio were obtained by application of higher dose of pure nitrogen in the form of Urea (Fig 3 and 6). Similar results were also obtained by Razieh et al, 2012, who also reported increased growth and development of plants by application of urea.

Table 1. Nutrient uptake and their significant response to N levels (N1, N2, N3) over control treatment (N0)

Treatment	Shoot N%	Root N%	Shoot C%	Root C %
N0	4.411a	2.657a	40.70a	37.27a
N1	4.356a	2.775a	41.81a	33.75b
N2	4.406a	2.858a	41.37a	32.05b
N3	4.879a	2.978a	40.45a	28.32c

Means within column followed by the same letter are not significantly different at 5% level by DMRT

Table 2: Effect of different doses of N on shoot & root N and C ratio and residual N% in soil

Treatment	Root and Shoot ratio (N)	Root and shoot ratio (C)	Soil residual N%
N0	0.5727a	0.9157a	0.02310d
N1	0.6375a	0.8076b	0.02657c
N2	0.6717a	0.7750b	0.03465b
N3	0.5871a	0.7024b	0.06122a

Means within column followed by the same letter are not significantly different at 5% level by DMRT

The interaction effect of nitrogen treatments was highly significant in root carbon absorption. Lower Nitrogen application provides higher carbon uptake in roots. This result also confirms the findings of Adrie and Oscar, 1996 who postulated the carbon content in roots increases upon nitrogen deprivation means higher carbon uptake by reduced nitrogen application. The nutrient uptake parameters are presented in table 1 and the data show that no significant difference was observed in nitrogen uptake in shoot, root and also carbon uptake in shoot among the treatments, except the root carbon absorption difference among the treatments which was highest in control. Also N0 contributed better root shoot carbon ratio compared to other 3 treatments (Table 2). These three treatments (N1-N3) did not show significant differences among themselves. The results in table 2 also clearly demonstrate that there was no significant difference in root shoot nitrogen ratio in all the treatments (N0-N3). However the results after harvesting the plants revealed the lowest residual Nitrogen in soil in the control treatment compared to highest nitrogen dose at N3 treatment in pots.

The different physiological and morphological parameters were affected by N0 (control) compared to N3, probably restricts metabolism activities affecting castor plant Growth. In contrast, at N3 crude protein concentration was also higher in the plant due to elevated nitrogen

levels (Fig 6) and provides the optimum growth of the plant. The result of the current experiment also revealed that the concentration of crude protein in castor plant increased with increasing doses of urea. This result also agrees with the findings of Silva et al 2005, Maryam and Dilek 2012, who reported that higher nitrogen application increased the plant crude protein content in plants.

The growth of aboveground and belowground parts of castor seedlings at different growth stages until the end of the experiment indicated that application of urea at a higher dose showed the best effect on plant development. This result also confirming the findings of Valadabadis et al 2011, who reported increase in castor plant yield due to elevated level of nitrogen. The residual N effect in soil was also highest with elevated nitrogen level (N3) followed by medium, lowest (N2, N1) and control (Table 2).

Maximum growth and developmental rates were achieved at N3. Even though all growth and developmental rates declined with lower N level, leaf length expansion rate was more sensitive to plant N followed by rates of petiole elongation and intermodal space addition. Among the plant components, shoot and root dry weight had the greatest decrease under N deficiency while root/shoot carbon ratio increased under N deficiency. These results also confirm the findings of Cheema and Abrar 2000, Nahar and Hoque 2013, Valadabadis et al 2011 and Razieh et al 2012, who reported increase in growth, development, yield and nutrient uptake in castor and other bean with increasing age and application of elevated level of nitrogen.

Conclusion:

On the average, evaluation of castor bean show that most of the investigated plant parameters were significantly affected by different N application and were more sensitive to N Deprivation. The plant was more suitable for cultivation with higher followed by moderate nitrogen application. Moreover, 120 lb/acre application was found the most suitable N application that can be suggested for castor bean in Washington State.

From the preceding discussion, it is concluded that the application of higher nitrogen per acre per year in the form of urea should be applied to castor plant for optimal growth, plant biomass and nutrient uptake in plants. Nitrogen requirement identified in this study could be used to estimate castor growth and development thus might be useful in managing crop N during the growing season. Nitrogen affects morphological and physiological processes in plants and accurate detection of plant N requirement can help farm managers to make appropriate N management decisions. In conclusion, the potential use of castor bean seeds for biodiesel production might be preceded by a much detailed work to be conducted until the stage of seed production.

References:

- AL-Tamimi, F. A., & Hegazi, A. E. (2008). A case of castor bean poisoning. Sultan Qaboos University Medical Journal, 8(1), 83.
- Akande, T.O., A.A. Odunsi and O.S. Adediji, 2011. Toxicity and nutritive assessment of castor (*Ricinus communis*) and processed cake in rat diet. *Asian J. Anim. Sci.*, 5, 330-339.

- 482
483 Alam, 2010. In vitro micro propagation through cotyledonary node culture of castor bean
484 (*Ricinus Communis* L.) *Aust. J. Crop Sci*, 4, 81-84.
485
- 486 Auld, D.L., Rolfe, R.D., McKeon, T.A., 2001. Development of castor with reduced toxicity.
487 *J. New Seeds* 3, 61–69.
488
- 489 Anonymous, 2009c. Castor bean (*Ricinus communis*) an internationalbotanical answer to
490 biodiesel production & renewableenergy. [http://www.dovebiotech.com/pdf/castor%20bean%20](http://www.dovebiotech.com/pdf/castor%20bean%20ricinus%20communis%20-%20biodiesel.pdf)
491 [ricinus %20 communis %20-%20biodiesel. pdf.](http://www.dovebiotech.com/pdf/castor%20bean%20ricinus%20communis%20-%20biodiesel.pdf) (Eriřim Tarihi: 25.09.2009).
492
- 493 Boulos, L. 1983. Medicinal plants of North Africa. Algonoc, Michigan Reference Publications,
494 Inc USA.
- 495 Bonjean, A., 2002. Castor. <http://www.ienica.net/crops/castor.htm>.
496
- 497 Blumenthal, J.M., Baltensperger, D.D., Cassman, K.G., Mason, S.G., Pavlista, A.D., 2008.
498 Importance and effect of nitrogen on crop quality and health. Published In *Nitrogen in the*
499 *Environment: Sources, Problems, and Management*, Second Edition.
500
- 501 Baldwin, B.S., Cossar, R.D., 2009. Castor yield in response to planting date at four locations in
502 the south-central United States. *Ind. Crops Prod.* 29, 316–319.
503
- 504 Boyer, J.S., 1982. Plant productivity and environment. *Science* 218, 443–448.
505
- 506 Bray, E.A., Bailey-Serres, J., Weretilnyk, E., 2000. Responses to abiotic stress. In: Caupin H.J
507 (1997) *Products from castor oil: Past, present, and future*. In: Gunstone FD and Padley FB (eds.)
508 *Lipid technologies and applications*. Marcel Dekker, New York, 787-795
509
- 510 Chapin III, F.S., 1980. The mineral nutrition of wild plants. *Annu. Rev. Ecol. Syst.* 1, 233–260.
511
- 512 Clarkson, D.T., Hanson, J.B., 1980. The mineral nutrition of higher plants. *Annu. Rev. Plant*
513 *Physiol.* 31, 239–298.
514
- 515 Cheema. Z.A. and A. Ahmed. 2000. Effects of Urea on the Nitrogen Fixing Capacity and
516 Growth of Grain Legumes. *Int. J. Agri. Biol.* 2(4):637-642
517
- 518 Cheema, N.M., Malik, M.A., Qadir, G., Rafique, M.Z., Nawaz, N., 2010. Influence of
519 temperature and osmotic stress on germination induction of different castor bean cultivars.
520 *Pakistan J. Bot.* 42, 4035–4041.
521
- 522 Cherry, N., 2009. Spilling the Beans About Castor Oil and its Derivatives. NCEED. Enterprises,
523 Inc. http://www.nceed.com/Spilling_the_Beans.pdf (Eriřim Tarihi: 28.09.2010).
524

- 525 Dufour, R.J., Shields, G.A., Talbot, R.J., 2003. Assessing microbial safety of drinking-water:
526 improving approaches and methods. World Health Organization (WHO) and Organisation for
527 Economic Cooperation and Development (OECD), IWA Publishing.
528
- 529 Duke, J.A., 1986. Handbook of
530 energycrops. http://www.hort.purdue.edu/newcrop/duke_energy/dukeindex.html. (Eriřim
531 Tarihi: 14.09.2009).
532
- 533 Deore A.J, Johnson TS (2008) High frequency plant regeneration from leaf-disc cultures of
534 *Jatropha curcas* L.: an important biodiesel crop. Plant Biotechnol Rep 2, 7-11
535
- 536 Derksen, J.T.P., Cuperus, F.P., Kolster, P., 1995. Paints and coatings from renewable
537 resources. Ind. Crops Prod. 3, 225–236.
538
- 539 Evans, J.R., 1983. Nitrogen and photosynthesis in the flag leaf of wheat (*Triticum eastivum* L.).
540 Plant Physiol. 72, 297–302.
541
- 542 FAO (Food and Agricultural Organization), 2006. <http://faostat.fao.org/>. Field, C., 1983.
543 Allocating leaf nitrogen for the maximization of carbon gain: leaf age as a control for the
544 allocation program. Oecologia 56, 341–347.
545
- 546 Field, C., Mooney, H.A., 1986. The photosynthesis–nitrogen relationships in wild plants. In:
547 Givinish, T.J. (Ed.), On the Economy of Form and Function. Cambridge University Press,
548 Cambridge, England, 25–55.
549
- 550 FAO., 2009. Statistical Database. <http://fao.org>. (Eriřim Tarihi: 20.11.2010).
551
- 552 Fetrow, C.W., Avila, J.R., 1999. Professional’s handbook of complementary and alternative
553 medicines. Springhouse, Pa: Springhouse Corp.
554
- 555 Fjällskog, M.L., Frii, L., Bergh, J., 1994. Paclitaxel-induced cytotoxicity the effects of
556 cremophor el (Castor Oil) on two human breast cancer cell lines with acquired multidrug
557 resistant phenotype and induced expression of the permeability glycoprotein.
558 Eur J Cancer., 30A: 687-690.
559
- 560 Farahani, H.A., Aref, B., 2008. Effect Of plant density on oil yield of castor (*Ricinus Communis*
561 L) in application of nitrogen levels conditions. African Journal of Traditional, Complementary
562 and Alternative medicines (AJTCAM). Ajtcam Issn: 0189-6016.
563
- 564 Gerik, T.J., Oosterhuis, D.M., Torbert, H.A., 1998. Managing cotton nitrogen supply. Adv.
565 Agron. 64, 115–147.
566
- 567 Glaser, L.K., Roetheli, J.C., Thompson, A.E., Brigham, R.D., Carlson, K.D., 1993. Castor
568 and Lesquerella: sources of hydroxy fatty acids. In: 1992 Yearbook of Agriculture.
569 USDA Office Publishing Visual Communication, Washington. 111–117.
570

- 571 Glass, A.D.M., 2003. Nitrogen use efficiency of crop plants: physiological constraints upon
572 nitrogen absorption. Crit. Rev. Plant Sci. 22, 453–470.
573
- 574 Jaynes, D.B., Colvin, T.S., Karlen, D.L., Cambardella, C.A., Meek, D.W., 2001. Nitrate loss in
575 subsurface drainage as affected by nitrogen fertilizer rate. J. Environ. Qual. 30, 1305–1314.
576
- 577 Kumari K.G, Ganesan M, Jayabalan N (2008) Somatic organogenesis and plant regeneration in
578 *Ricinus communis*. Biol Plantarum 52, 17–25
579
- 580 Kafagi, I.K. 2007. Variation of callus induction and active metabolic accumulation in callus
581 cultures of two varieties of (*Ricinus communis* L.) Biotechnology 6, 193–201.
582
- 583 Kalimantan, E., 2011. Building the total productive value-chain for operations ranging from
584 cultivation of castor oil plant seeds to integrated production of castor oil, Sebacic Acid and
585 Nylon Resin Project. Consulting Services Report for Introducing High Energy Efficiency
586 Facilities. Japan Consulting Institute. Toray International, INC.
587
- 588 Kittoch, D.L., Williams, J.H., 1967. Castorbean production as related to length of growing
589 season. I. Effect of date of plant desiccation. Agronomy Journal, 59, 438–440.
590
- 591 Kingston-Smith, A.H., Bollard, A.L., Minchinand, F.R., 2006. The effect of nitrogen status on
592 the regulation of plant-mediated proteolysis in ingested forage: an assessment using non-
593 nodulating white clover. Ann. Appl. Biol. 149, 35–42.
594
- 595 Kittoch, D.L., Williams, J.H., 1970. Effects of plant population on castor bean yield.
596 Agron. J. 62, 527–529.
597
- 598 Luseba, D., Elgorashi, E.E., Ntloedibe, D.T., Van Staden, J., 2007. Antibacterial, anti-
599 inflammatory and mutagenic effects of some medicinal plants used in south africa for treatment
600 of wounds and retained placenta in livestock. South African Journal of Botany, 73, 378–383.
601
- 602 Lehav, E., J.E. Harper and R.H. Hugeman. 1976. Improved soybean growth in urea with pH
603 buffered by carboxy resin. Crop. Sci, 16, 325–328
604
- 605 Mengel, K., Hütsch, B., Kane, Y., 2006. Nitrogen fertilizer application rates on cereal crops
606 according to available mineral and organic soil nitrogen. Eur. J. Agron. 24,
607 343–348.
608
- 609 Murphy, D.J., 1993. Structure, function and biogenesis of storage lipid bodies and oleosins in
610 plants. Prog. Lipid Res. 32, 247–280.
611
- 612 Maryan P and Dilek.B. 2012. The effects of different nitrogen doses on yield and some
613 agricultural characteristics of castor bean plant (*Ricinus communis* L.) Iğdir Univ. J. Inst. Sci&
614 Tech. 2(2):83–92.
615
- 616 Narits, L., 2010. Effect of nitrogen rate and application time on yield and quality of winter oilseed
617 rape (*Brassica napus* L. var. *oleifera* subvar. *biennis*). Jõgeva Plant Breeding Institute;

- Aamisepa 1, 48309 Jõgeva, Estonia; Agronomy Research 8(Special Issue III), 671-686.
- Nahar.K.,S. A. Sunny and S. S. Shazi, 2011. Land Use requirement and urban growth Implications for the production of biofuel in Bangladesh. *Canadian Journal on Scientific and Industrial Research*. 2(6): 195-208.
- Nahar.K and R. Borna 2012.*In vitro* Propagation from Shoot tip Explants of Castor oil plant (*Ricinus communis* L): A Bioenergy Plant.Canadian Journal on Scientific and Industrial Research 3 (5): 254-255.
- Nahar.K. and S. Hoque 2013.Castor Bean (*Ricinus communis* L.) - A Biofuel Plant: Morphological and Physiological Parameters Propagated from Seeds in Bangladesh. *Asian Business Review*. 2(4):64-66.
- Novero, A. U. and Jamiri, F. 2012. Plant Regeneration through Direct Shoot Formation from Sago Palm (*Metroxylon sagu* Rottb.) Leaf Explants. *Asian J. of Biotechnology* 4 (2): 92 – 99
- Ombrello, T., 2009. Kinetic ignition enhancement of diffusion flames by nonequilibrium agnetic gliding arc plasma. *AIAA Journal*, 46(10): 2424-2433.
- Onwuliri, V.A., Anekew, G.E., 2001. Amino acids and other biochemical component of *Ricinus communis* variety minor, an anti-conceptive seed. Department of Biochemistry, University of Joe,West Arica.
- Oplinger, E.S., Oelke, E.A., Kaminski, A.R., Combs, S.M., Doll, J.D., Schuler, R.T., 1990. Castor Beans. http://www.hort.purdue.edu/newcrop/duke_energy/Ricinus_communis.html
- Osava, M., 2003. Energy in a castor bean (online). <http://www.tierramerica.net/english/2003/0526/ianalisis.shtml> (accessed 02.08.05; verified 26.02.06).
- Ogunniyi, D.S. 2006. Castor Oil: A vital Industrial raw material. *Biosource technology*, 97,1086-1091.
- Parry, M.A.J., Flexas, J., Medrano, H., 2005. Prospects for crop production under drought: research priorities and future directions. *Ann. Appl. Biol.* 147, 211–226.
- Peuke, D.A., Dieter, J.W., Wolfram, H., 1994a. The uptake and flow of C, N and ions between roots and shoots in *Ricinus communis* L. II. Growth with low or high nitrate supply. *J. Exp. Bot.* 45, 733–740.
- Peuke, D.A., Dieter, J.W., Wolfram, H., 1994b. The uptake and flow of C, N and ions between roots and shoots in *Ricinus communis* L. III. Long-distance transport of abscisic acid depending on nitrogen nutrition and salt stress. *J. Exp. Bot.* 45, 741–747.

- 663 Pimentel, D., Patzek, T.W., 2005. Ethanol production using corn, switchgrass, and wood:
664 biodiesel production using soybean and sunflower. *Nat. Resour. Res.* 14, 65–76.
665
- 666 Pohlmeier, A., 2007. Change in soil water content resulting from *Ricinus* root uptake monitored
667 by magnetic resonance imaging. *Vadose zone journal*. 7, 1010-1017.
668
- 669 Silva P; Mércio L.S; Rúbia C; Lisandro R; Luís .S; Gilber A; Everton F; Adriano S. 2005. Grain yield
670 and kernel crude protein content increases of maize hybrids with late nitrogen side dressing. *Sci. Agric.*
671 62(5): 487-492
672
- 673 Radin, J.W., Boyer, J.S., 1982. Control leaf expansion by nitrogen nutrition in sunflower plants:
674 role of hydraulic conductivity and turgor. *Plant Physiol.* 69,771–775.
675
- 676 Razieh khalilzadeh., Mehdi Tajbakhsh and Jalal Jalilian. 2012. Growth characteristics of mung
677 bean (*Vigna radiata* L.) affected by foliar application of urea and bio-organic fertilizers. *Intl J*
678 *Agri Crop Sci.* 4 (10): 637-642,
679
- 680 Roetheli, J.C., L.K. Glaser, and R.D. Brigham. 1991. Castor: Assessing the feasibility of U.S.
681 production. Workshop summary, Plainview, TX, Sept. 18-19, 1990. USDA/CSRS Office of Agr.
682 Materials. Growing Ind. Material Ser.
- 683 Riazuddin, S., R. Islam, F. Tahera and T. Husnain. 2012. Plant Regeneration and Expression of
684 Beta-glucuronidase Gene in Hypocotyl Tissues of Chickpea (*Cicer arietinum* L.) *Asian Journal*
685 *of Biotechnology* 4 (2): 92 – 99
686
- 687 Reddy, A.R., Reddy, K.R., Padjung, R., Hodges, H.F., 1996. Nitrogen nutrition and
688 photosynthesis in leaves of Pima. *J. Plant Nutr.* 19,755-770.
689
- 690 Reddy, K.R., Matcha, S.K., 2010. Quantifying nitrogen effects on castor bean (*Ricinus*
691 *communis* L.) development, growth, and photosynthesis. *Ind. Crops Prod.* 31,185–191
692
- 693 Reddy, K.R., Hodges, H.F., McKinion, J.M., 1997a. Crop modeling and applications: a cotton
694 example. *Adv. Agron.* 59, 225–290.
695
- 696 Reddy, K.R., Hodges, H.F., Mckinion, J.M., 1997b. Modeling temperature effects on cotton
697 internode and leaf growth. *Crop Sci.* 37, 503–509.
698
- 699 Roggatz, U., McDonald, A.J.S., Stadenberg, I., Schurr, U., 1999. Effects of nitrogen deprivation
700 on cell division and expansion in leaves of *Ricinus communis* L. *Plant Cell Environ.* 22, 81–89.
701
- 702 Ryle, G.J.A., C.E. Powel and A.J. Gordon, 1978. Effect of source of nitrogen on the growth of
703 Fiskeby Soybean. The carbon economy of whole plants. *Ann. Bot(London)* 42,637-648.
704
- 705 Rajarathinam, A. and R. S. Parmar. 2001. Application of Parametric and Nonparametric
706 Regression Models for Area, Production and Productivity Trends of Castor (*Ricinus communis*
707 L.) *Crop. Asian Journal of Applied Sciences.* 4 (1): 42 – 52.

- 708
709 Raven P.H., R.F, Evert and S.E Eichorn.1999. Biology of Plant. 6th edition. New York: W.H
710 Freeman and Company, 1,11-15
711
712 Silva. P.,Mércio, L. S.,Rúbia P. S. C.,Lisandro R.,Luís, S., Gilber. A.,Everton L. F. and Adriano A. S.
713 2005 Grain yield and Kernel Crude Protein content increases of Maize hybrids with late nitrogen side
714 dressing. Sci. Agric. (Piracicaba, Braz.). 62(5):.487-492.
715
716 Sinclair, R.O., Horie, T., 1989. Leaf nitrogen, photosynthesis, and crop radiation use efficiency:
717 a review. Crop Sci. 29, 90–98.
718
719 Stewart, W.M., Dobb, D.W., Johnston, A.E., Smith, T.J., 2005. The contribution of commercial
720 fertilizer nutrients to food production. Agron. J. 97, 29–32.
721
722 Shafiee, S., Hashemi, J., Kheiralipur, K., 2009. Moisture dependent physical properties of
723 castorbean seeds. World Applied Sciences Journal, 1216-1221.
724
725 Shams, A., Moursi, M. A., Ahmed, S.S., 1967. Effects of nitrogen and spacing on castor bean in
726 sandy soils in Egypt. Cairo University.U.A.R. National Research Centre and Faculty of
727 Agriculture. 61-64.
728
729 Severino, L.S., Auld, D.L., Baldanzi, M., Cândido, M.J.D., Chen, G., Crosby, W., et al.,2012a. A
730 review on the challenges for increased production of castor. Agron. J.104 (853–880).
731
732 Severino, L.S., Auld, D.L. 2013.A framework for the study of the growth and development of
733 castor plant. Industrial Crops and Products 46, 25– 38
734
735 Valadabadi S.A.R., Alimohammadi M, Aref B., Daneshian J. 2011. Effects of different levels of
736 nitrogen and plant density on oil yield and its components of castor(*Ricinus Communis* L.).
737 Journal of crop Ecophysiology. 2(4):321-318.
738
739 Vignolo, R., Naughton, F., 1991. Castor: a new sense of direction. Int. News Fats Oils Relat.
740 Mater. 2,692–699.
741
742 Watson, D.J., 1952. The physiological basis of variation in yield. Adv. Agron. 4, 101–145.
743
744 Weiss, E.A., 1971. Castor, Sesame, and Safflower. Leonard Hill, London.
745
746 Weiss, E.A., 2000. Oilseed Crops, 2nd ed. Blackwell Science, Oxford.

747 Werf.A and O.Nagel. 1996. Carbon allocation to shoots and roots in relation to nitrogen supply
748 is mediated by cytokinis and sucrose: Opinion. Plant and Soil. 185(1): 21-32

749 Wong, S.C., 1979. Elevated atmospheric partial pressure of CO₂ and plant growth. I. Interactions
750 of nitrogen nutrition and photosynthetic capacity in C₃ and C₄ plants. Oecologia (Berlin) 44, 68–
751 74.
752

753 Zhao, D., Reddy, K.R., Kakani, V.G., Read, J.J., Carter, G.A., 2003. Corn (*Zea mays* L.) growth,
754 leaf pigment concentration, photosynthesis and leaf hyperspectral reflectance properties as
755 affected by nitrogen supply. *Plant Soil* 257,205–217.

756
757 Zhao, D., Reddy, K.R., Kakani, V.G., Read, J.J., Koti, S., 2005a. Selection of optimum
758 reflectance ratios for estimating leaf nitrogen and chlorophyll concentrations of
759 field-grown cotton. *Agron. J.* 97, 89–98.

760
761 Zhao, D., Reddy, K.R., Kakani, V.G., Reddy, V.R., 2005b. Nitrogen deficiency effects on
762 plant growth, leaf photosynthesis, and hyperspectral reflectance properties of
763 sorghum. *Eur. J. Agron.* 22, 391–403.

764
765 Zhao, D., Reddy, K.R., Kakani, V.G., Read, J.J., Koti, S., 2007. Canopy reflectance in cotton for
766 growth assessment and prediction of lint yield. *Eur. J. Agron.* 26,335–344

767

768