

The Distribution of Dry Matter in Bean Seedlings in Light and Darkness Conditions

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1. Introduction

Plants express different stages of development to complete their life cycle, where in each phase have different demands on nutrition and the distribution of photosynthates among the structures. Thus, during growth, the plant accumulates and allocates different proportions of dry matter to their structures and root.

In the seed is the embryo formed by the radicle and plumule, and cotyledons. They have stored nutrient reserves that proportion to the embryo that originate the root and plumule forms the stem and leaves of the seedling. The seeds can contain one cotyledon as monocotyledons such as maize, two in dicotyledonous plants such as beans and many cotyledons in gymnosperms. The seedling formed the hypocotyl located between the root and cotyledons and the epicotyl which includes the stem and plumule formed above the cotyledons.

In a bean seedling formed are defined the root system which consists of the main root, adventitious roots, primary roots, secondary and tertiary roots and stem consists of the hypocotyl, cotyledons, epicotyl, simple leaves, first trifoliolate leaf and second trifoliolate leaf. Each structure complies with specific functions to maintain growth and seedling development. The roots absorb water and minerals and the vegetative part absorbs the solar radiation to produce the photosynthate that nourish the seedling.

In the germination of the seed resumes growth by activating the metabolism of the embryo, which occurs when the seed absorbs water available around them and ends when specifically embryonic radicle elongates (Bidwell, 1990; Mayer and Poljakoff, 1989). From a practical standpoint, it is considered that germination is complete when the radicle has emerged from the shell and from this moment is considered the growth of the seedling. During germination different biochemical and morphological processes perform and it marks the beginning of the decline in reserves in the cotyledons and their exportation, which is accompanied by an increase in respiration (Bathellier et al., 2008). The first structure that appears in the seed is the radicle, which grows down, then hook plumule emerges as part of the hypocotyl and first structure that comes into contact with the light so soon chlorophyll activates and triggers photosynthesis.

After the germination, growth begins, which leads to establish the seedling ranging from when the seedling emerges from the ground until it becomes autotrophic (Holman and Robbins, 1982). In light, the seedlings quickly initiate the synthesis of photosynthates and

ensure their establishment (Mayer and Poljakoff, 1989). Seedlings emerge in darkness, they continue to grow until senescence and die without being autotrophic (Bidwell, 1990).

The nutrition of the seedling is done by the translocation of photosynthates and nutrients from germination and in all development. There are two concepts that explain the translocation of nutrients called "source" conceived as the regions of nutrient export and "demand" that are the places of import (Wolswinkel, 1992). Thus establishing a nutrient concentration gradient between the two regions, which move through the vascular system (Ho et al., 1989). During the germination process is initiated the mobilization of seed reserves from the cotyledons to the embryonic axis. This process continues until the seedling stage, in which the primary sources are exhausted and the seedling becomes autotrophic to form leaves that carry out photosynthesis, which are the most important source of photosynthate of the plant (Bewley and Black, 1985; Ho et al., 1989). The first regions of demand are the apical meristems of the plumule and radicle. Later, during the plant development, the diverse meristems of stem and root apical meristems are the sites of most intense demand (Eschrich, 1989).

The accumulation of dry matter in seedlings developed in light and darkness is different because in each condition, the amount of nutrients available to the seedling is different. Seedlings show marked differences in morphology and proportions of distribution and allocation of dry matter in the structures and root that are formed. Therefore, this chapter describes the dynamic allocation of dry matter in bean seedlings developed in conditions of light and darkness.

2. Materials and methods

2.1 Establishment of experiments

Two experiments were installed in light conditions, one in greenhouse and the other in a growth chamber at constant temperature of 25°C. In darkness, the seeds were sown in a dark room and in a growth chamber at 25°C.

The planting of bean cultivar Cacahuet-72 habit type I (Debouck and Hidalgo, 1985) was realized in transparent polyethylene cylindrical tubes of 14 cm of diameter and 70 cm of length. The tubes were filled with sand washed with water. The seed was placed at 2.5 cm depth after irrigation to field capacity. The seed was placed with the micropyle toward up and the lens down, in order to facilitate the growth of the radicle. Seeds sown weighed between 290 and 300 mg per seed.

2.2 Management of seedlings

In the light experiment there were five samples at 8, 13, 18, 21 and 25 days after sowing. The sample size was of two seedlings in the first and second sampling, and three in the remaining. In dark conditions some samples were obtained at 2, 5, 8, 11, 13, 18, 21, 25, 29, 32 days.

Seedlings in dark were observed with green light by a flashlight covered with three layers of green cellophane paper. The light is commonly used as a security light in physiology experiments mainly where phytochrome is involved because it keeps the photostationary state between Pr and Pfr forms because these pigments are not effective at absorbing green light. In addition, our eyes are sensitive to this light and allows us to visual perception (Smith, 1975; Salisbury and Ross, 1994).

Seedlings were removed from the tubes getting the whole root tubes cut longitudinally and the roots were freed from the sand with water. To avoid desiccation of the seedlings they were placed on paper newspaper. Each seedling was dissected into its various structures, which were analyzed for fresh weight and then dried to constant weight (80°C) for 48 hours to obtain dry weight. Both the dry and fresh weight were obtained in an analytical balance. The roots are separated by category, taproot, adventitious, secondary and tertiary.

2.3 Shoot structures

Structure was called to each of the parts of the stem, which include cotyledons, epicotyl, hypocotyl and radicle. The last three structures form the embryonic axis. The plumule are all parts located above the cotyledons that including apical meristems. Epicotyl was named to the portion of the stem between the cotyledons and the first simple leaves, hypocotyl to the structure located between the cotyledons and the neck of the root differentiated by a concave line in the root observed between these two parties. The simple leaves are formed in the second node in the opposite way.

2.4 Classification of roots

The bean root system is characterized by a taproot. Roots arising from it are called secondary roots, those formed from them is called tertiary roots. Adventitious roots were formed at the base of hypocotyl.

2.5 Use of reserves

In order to know the initial distribution of dry matter in the seed, 20 of them were used from 290-300 mg in weight, which were soaked. They were then separated the shell, cotyledons and embryonic axis were placed in petri dishes and dried to a constant weight at temperature of 80°C for 48 hours to get weight on analytical balance.

The dry matter contained in the cotyledons is metabolizable dry matter (which is the reserve material) and non metabolizable (which is what constitutes the cell walls). The amount of reserves of the cotyledons was considered its initial dry weight minus the dry weight when they reach their constant weight after drying representing the structural matter of the cotyledons (non-metabolizable dry matter).

2.6 Determinación of the root/shoot

In each sample were estimated the root/shoot dry weight relation by dividing the dry weigh of root and the dry weight of shoot.

3. Results and discussion

The embryonic axis consists of the plumule and radicle, which demands nutrients from the seed when germination begins, which are provided by the cotyledons. The nutrients are sufficient until the hook plumule emerges and makes contact with sunlight to start photosynthesis. As the cotyledons have nutrient reserves, the seedling can live without performing photosynthesis. However, when the seedling is not exposed to sunlight show etiolation and dies soon at the time that deplete nutrients in the cotyledons. This establishes the relationships between growth of the shoot, root and provides nutrients from the

cotyledons (McDonald, 1994), which can be expressed by dry matter accumulation in the stem and root and to lose dry matter of cotyledons.

3.1 Accumulation of dry matter

Bean seedlings planted under light conditions accumulate dry matter during their development (Figure 1). The same occurs with the shoot and root. However, the cotyledons decreased dry weight. This is because these structures provide nutrients to the shoot and root. The dry matter accumulation in the seedling and the different structures forming are the product of the translocation of nutrients from the cotyledons and the photosynthesis performed. For this reason the cotyledons tend to lose dry weight during the seedling growth and become shoot structures dying first (Díaz-Ruiz et al., 1999). According to Bathellier et al. (2008), during imbibition of the seed, cotyledons mass decrease slowly but after three days it was found that accelerated markedly. Shoot accumulates more dry matter than the root which is possibly due to greater number of structures that require significant amounts of nutrients. This occurs from the beginning of germination, this tendency has been reported in cotton plants developed under light (De Souza and Da Silva, 1987).

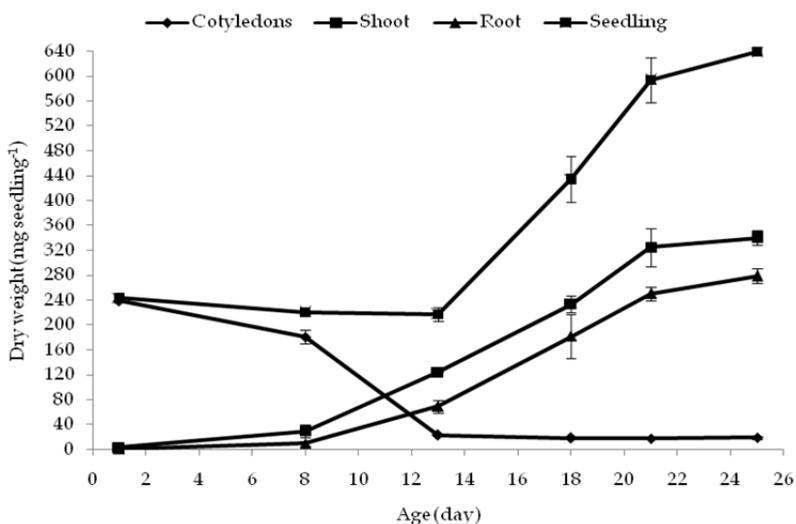


Fig. 1. Dry matter accumulation in bean seedlings developed in light. The bars represent the standard deviation.

Seedlings grown in darkness tend to decrease their dry matter during development up to senescence (Figure 2). The dry matter in shoot and root increased from emergence to 13 days and then tend to decrease their dry weight. Cotyledons reduced its dry weight because they are the only structures that provide nutrients to the seedling. The shoot and root depends on the amount of nutrients stored in the cotyledons for their growth. Both in darkness and in light, the shoot accumulate greater quantity of dry matter than the root with the difference being greater the accumulation in darkness than in light. Under darkness the only source of nutrients are the cotyledons, when they run out the shoot and root dry weight decreased and die (Díaz-Ruiz et al., 1999).

By comparing the growth of bean seedlings in light and darkness conditions, it is clear that the dry matter accumulation in darkness depends exclusively on the reserves of the cotyledons which were reflected in the correlation between weight gain in shoot and root and dry weight loss of the cotyledons. Under light conditions, the cotyledons perform photosynthesis, but their contribution is minimal compared to the first leaf blade which was determined by Harris et al. (1986) in soybeans. This indicates that their main function is to provide photosynthates that have stored to the seedling. However, photosynthesis of cotyledons helps balance the energy loss through respiration until the first leaf performs full photosynthesis (Harris et al., 1986). Even if the seedlings grown in darkness were exposed to light, the content chlorophyll increases and activates. Maricle (2010) reported that etiolated seedlings by exposing to light for four days increased the chlorophyll. In general, beans and wheat are species when exposed to light rapidly develop chlorophyll and increase the activity of catalase (Maricle, 2010). The early declines in dry matter of the cotyledons of bean seedlings have been reported by Barthellier et al. (2008).

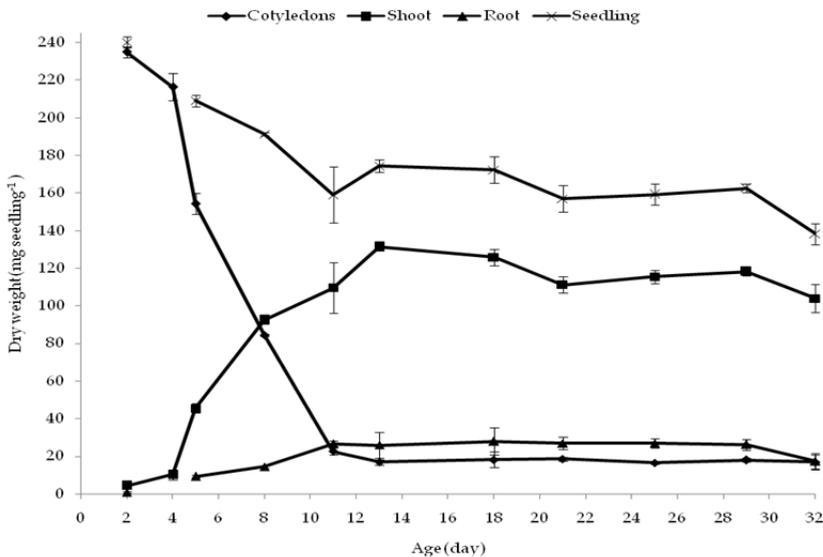


Fig. 2. Dry matter accumulation in bean seedlings developed in darkness. The bars represent the standard deviation.

3.2 Distribution of dry matter

The dry matter in seedlings developed with light is distributed in different proportions to be tangible in the early days, in this case at 8 days after planting (Figure 3). When the cotyledons reach their maximum nutrients, shoot and root tend to stabilize the distribution of photosynthates, where the shoot becomes more dry matter than the root which is greater than 50%. Although the shoot is composed of more structures such as leaves and stem, the root is channeled a significant amount of dry matter. The cotyledons are the only structures of seedling that stabilize dry matter reaching around 3%. These structures serve the function of supplying photosynthate to the shoot and root and themselves. While performing

photosynthesis their life is short and so are the first structures to die and slough of the shoot. Dry matter detected in them to reach senescence is not metabolizable. The transfer of more dry matter to shoot was also recorded by Metivier and Paulilo (1980) in bean, they also found that storage proteins were transferred faster than dry matter.

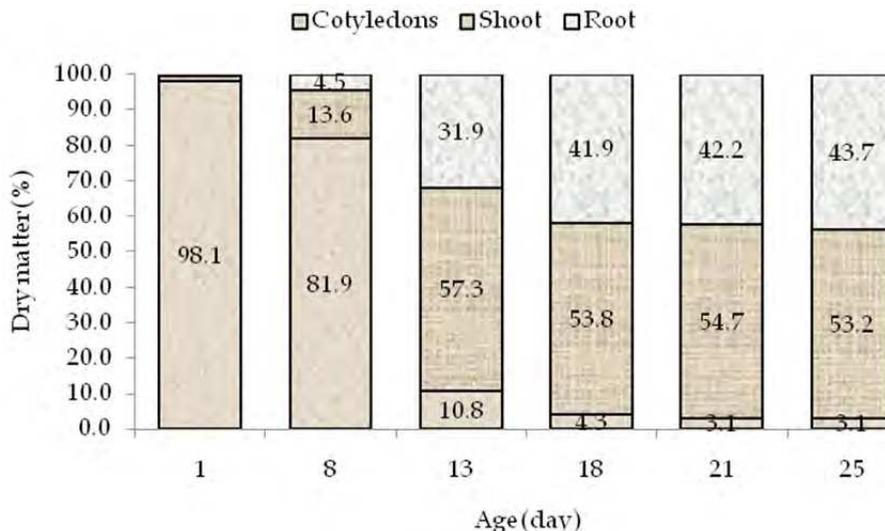


Fig. 3. Distribution of dry matter in bean seedlings developed in light.

The distribution of dry matter in seedlings developed in darkness is different compared to seedlings in light. In this condition, the cotyledons have a similar trend with the decisive role of supplying nutrients to the shoot and root because it is the only source of reserves, in this case do not perform photosynthesis, so its depletion is faster. Thus, 8 days after sowing cotyledons in darkness contain 44.1% dry matter (Figure 4) and in light conditions have 81.9% (Figure 3) which is twice the dry matter. The shoot is the structure which holds as much dry matter in relation to the root as happens in light conditions, the difference is the amount that accumulates in darkness is over 70% and around of 53% in light. In contrast, the accumulation of matter in the root is significantly lower, in the darkness is about 16% and around of 42% in light. Thus, in light of dry matter distribution is more equitable between the shoot and root compared with the distribution occurred in darkness.

3.3 Water content

The seedlings developed under light, mg of water presented an upward trend, the same happen in the stem and root (Table 1). The cotyledons expressed a slight ascent to 8 days and then tended to decline. The stem was the structure with more water content after 8 days. The seedling was a maximum of 2390.2 mg. In mg of water showed a significant difference both in structures and in the seedling, but the differences in water content were not very different, indicating a trend towards a stable proportion of water in the range of 85 to 90% mainly in the new tissue, which go forward age, the water decreases and the dry matter increases.

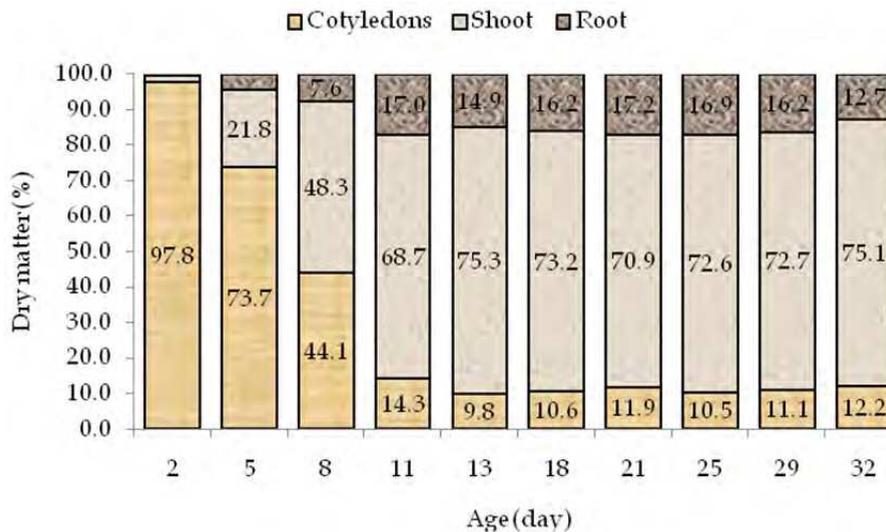


Fig. 4. Distribution of dry matter in bean seedlings developed in darkness.

Age (day)	Cotyledons		Shoot		Root		Seedling	
	mg	%	mg	%	mg	%	mg	%
2	279.0 ±3.6	54.4 ±0.7	20.6 ±2.7	86.0 ±0.6	2.3 ±0.5	85.9 ±1.8	301.9 ±2.2	56.0 ±1.0
8	289.3 ±45.3	75.4 ±1.9	728.7 ±132.6	92.2 ±0.7	207.9 ±61.4	91.4 ±0.8	1225.9 ±79.7	87.4 ±1.1
13	120.7 ±20.6	85.8 ±1.7	1288.3 ±93.0	90.6 ±9.5	581.2 ±158.2	89.7 ±1.6	1990.1 ±90.6	90.1 ±4.2
18	109.3 ±13.0	87.4 ±1.0	1593.0 ±82.0	86.5 ±0.5	687.9 ±159.1	84.7 ±4.3	2390.2 ±84.6	89.3 ±1.9

Table 1. Water content in bean seedlings developed in light.

In dark conditions, the seedling, cotyledons, shoot and root showed upward trends and then down in water content (Table 2), which was more tangible in the cotyledons. Seedlings reached a maximum water content equal to 3379.7 mg (13 days). The seedling, shoot and root showed a water content greater than 90%. Cotyledons water accounted for more than 80% but less than 90%. At roots, the water content tended to decrease (13 days) first than in the shoot (22 days). In the cotyledons, the increase in water content at the beginning is attributable to imbibition process and then the fact that the water content drops more slowly than dry weight, coupled with these, there is little loss of water by transpiration because the substrate in which plants were sown always remained wet.

Seedlings more water stored in darkness than in light, however in both conditions the amount of water tended to decrease. In darkness is attributable to the decrease of dry matter which coincides with the senescence of seedlings, shoot and root, in the light, is attributable to the tissue becomes more fibrous and accumulation in higher dry matter, of thus the water becomes less retained. Both in light and in darkness, the cotyledons did not exceed more

than 90% water and was markedly decreased between 13 and 18 days in darkness in relation to the occurred in light

Age (day)	Cotyledons		Shoot		Root		Seedling	
	mg	%	mg	%	mg	%	mg	%
2	318.0 ±19.1	57.5 ±1.4	33.6 ±4.1	88.5 ±0.7	8.1 ±1.4	89.6 ±1.7	359.7 ±8.2	59.9 ±1.3
5	360.3 ±17.5	70.0 ±0.8	730.3 ±82.6	94.1 ±0.4	164.0 ±12.2	94.6 ±0.5	1254.6 ±37.4	85.6 ±0.6
8	212.0 ±8.0	82.8 ±1.9	2124.0 ±48.2	95.6 ±0.2	274.3 ±9.6	95.0 ±0.2	2610.3 ±21.9	94.4 ±0.8
13	97.7 ±8.3	83.9 ±1.5	2916.7 ±63.2	96.3 ±0.2	365.3 ±57.5	94.6 ±1.7	3379.7 ±43.0	95.6 ±1.1
18	29.6 ±12.4	60.9 ±6.8	2662.7 ±141.2	96.1 ±0.3	121.2 ±50.0	85.4 ±4.7	2813.5 ±67.9	95.0 ±3.9
22	3.0 ±1.0	15.5 ±4.9	1648.7 ±127.1	95.0 ±0.3	79.8 ±11.0	79.8 ±3.3	1731.5 ±46.4	93.2 ±2.8

Table 2. Water content in bean seedlings developed in darkness.

3.4 Dry matter ratio root/shoot

In light-grown seedlings, the ratio derived from the root/shoot tended to increase as was occurring seedling growth (Table 3). Up to 18 days, the ratio significantly increased from 0.32 to 0.78, then remained in stable values. It is likely that the trend expressed is due to the lack of fertility in the substrate. Initially, the increase in rates due to the instability of the dynamics of dry matter allocation to shoot and root, then the proportions of dry matter were more defined, which was reflected in a disparity in rates.

Age (day)	Light	Darkness
8	0.32 ±0.04	0.16 ±0.01
13	0.55 ±0.08	0.20 ±0.06
18	0.78 ±0.16	0.22 ±0.06
21	0.77 ±0.07	0.24 ±0.02
25	0.82 ±0.06	0.23 ±0.02
29	-	0.22 ±0.03

Table 3. Ratio dry matter of root/shoot in bean seedlings developed in darkness and light.

In dark conditions the root/shoot had its largest increase between 8 and 13 days, after the increases were minimal. The maximum value of root/shoot was 21 days. The indexes were having minimal increases from 13 days, when the stem presented slight increases of dry matter and the root remained more constant. Velazquez-Mendoza (1989) found in beans under drought increased root/stem indexes, which were attributed to greater distribution of nutrients to the root at the expense of stem and leaves. In our case, we observed a similar trend after the cotyledons contributed the most assimilated.

In light conditions higher rates of root/shoot were obtained than in dark conditions at all ages sampled. This indicates that the root/shoot may increase with the supply of nutrients

to the seedlings, in light were supplied of photosynthates by the cotyledons and leaves and in darkness were consumed the reserves of the cotyledons only.

3.5 Dry matter in shoot structures

In the seedlings developed under light all the structures of both the shoot and the roots tended to increase dry matter accumulation (Figure 5). The leaves accumulated more dry matter in all samples except at 8 days. Adventitious and secondary roots had higher dry matter than the other structures of the stem and taproot after 18 days except for simple leaves. Similarly at 18 days dry weight was higher in the hypocotyl than the epicotyl and main root. In the seedling stage the leaves become the main source of photosynthates replacing the cotyledons reach senescence. This indicates that the flow of nutrients begins in the cotyledons and continues in simple leaves, so it takes the largest proportion of nutrients from the cotyledons during the early days, from germination until the leaves are coming almost half of growth in dry matter accumulation. The transition from simple leaves of source organ to of demand organ is associated with its ability to form photoassimilates and maintain a balance between their synthesis and use by itself (Loescher et al., 1982). Thus, after senescence of cotyledons, simple leaves senescence start, when this happens, the first compound leaf begins to provide photosynthate to the seedling. In this moment is important to apply fertilizer to the seedling to meet the demand for nutrients (Díaz-Ruiz et al., 2008).

Adventitious and secondary roots are most important at this stage, obtain more dry weight which is marked at 18 days. Thus, the water absorption in the seedling depends on these two types of roots. In addition to the above, the increased demands for nutrients in the roots are the adventitious roots and secondary roots. For his part in the shoot are simple leaves and the hypocotyl.

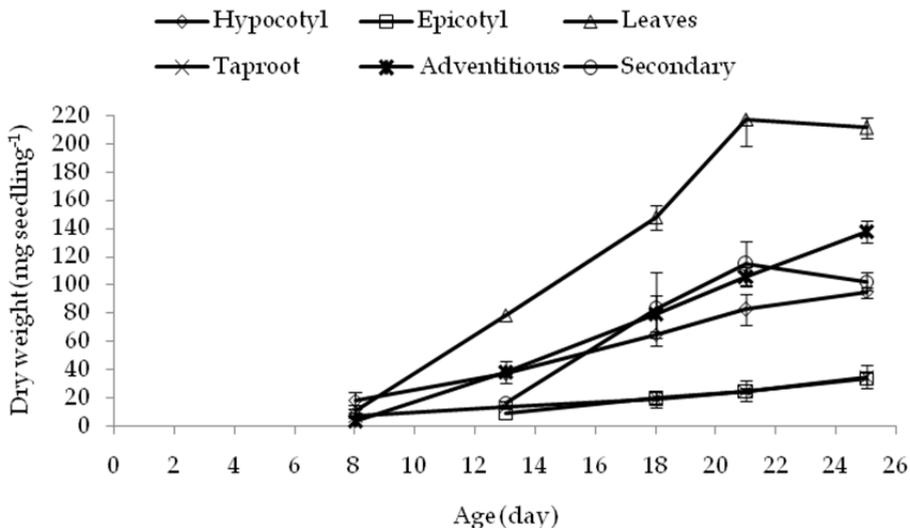


Fig. 5. Dry matter accumulation in the structures of shoot and root of bean seedlings developed in light. The bars represent the standard deviation.

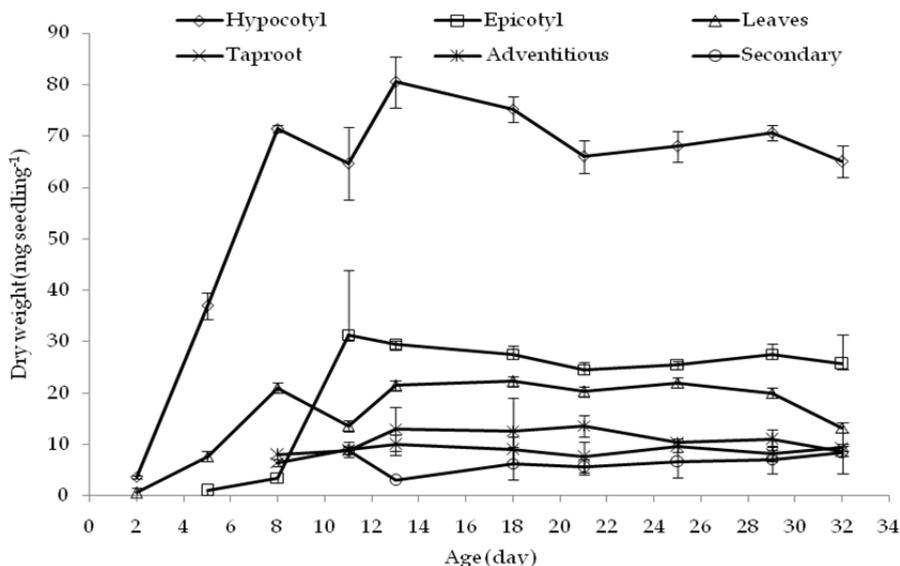


Fig. 6. Dry matter accumulation in the structures of shoot and roots of bean seedlings developed in darkness. The bars represent the standard deviation.

In darkness conditions, dry matter accumulation was different to that observed in seedlings with light. Shoot structures and the different types of roots showed a sigmoid trend (Figure 6), except in secondary roots was not observed clearly. Up to 13 days the dry matter accumulation in the root and structures was evident, after being stable and tended to decrease. The dry matter accumulation in the hypocotyl was significant compared to other structures and roots. In general stem structures accumulated more dry matter than roots. The order from highest to lowest accumulation was as follows: hypocotyl, epicotyl, leaves, adventitious roots, taproot and secondary roots. The decrease in dry matter was strongest in the hypocotyl, after the cotyledons exhausted most of its reserves. This could indicate the translocation of nutrients from other structures, as well, the hypocotyl was commissioned to provide nutrients to other structures to keep them alive, so the decrease in dry weight of roots and other structures is less pronounced, however, the nutrients provided are not sufficient to continue increasing in dry weight.

Adventitious roots formed first secondary roots extract nutrients from the cotyledons first and then the base of the hypocotyl.

3.6 Distribution of dry matter in shoot structures

In the seedlings developed under light gives greater amount of dry matter to leaves, which occurred from 13 days (Figure 7). At 8 days, more dry matter was assigned to the hypocotyl, followed by the leaves. The formation of new organs influences the distribution of dry matter in the seedling, thus, after 13 days the dry matter distribution tends to be constant. Under these conditions, the dry matter production of seedlings is a function of the photosynthate produced in primary leaves, so if there is damage to them, the growth of the seedling is affected. Thus, Hodgkinson and Baas-Becking (1977) indicate that the defoliation causes death roots and decrease its ramifications. However, maintaining carbohydrate stores that allow

them to survive (Buwai and Trlica, 1977). In the shoot, the structures with greater allocation of dry matter are the leaves and the hypocotyl and in the roots are adventitious and secondary roots. It is likely that the roots, the taproot becomes less important and the role of nutrient uptake and soil water is realized by adventitious roots and secondary.

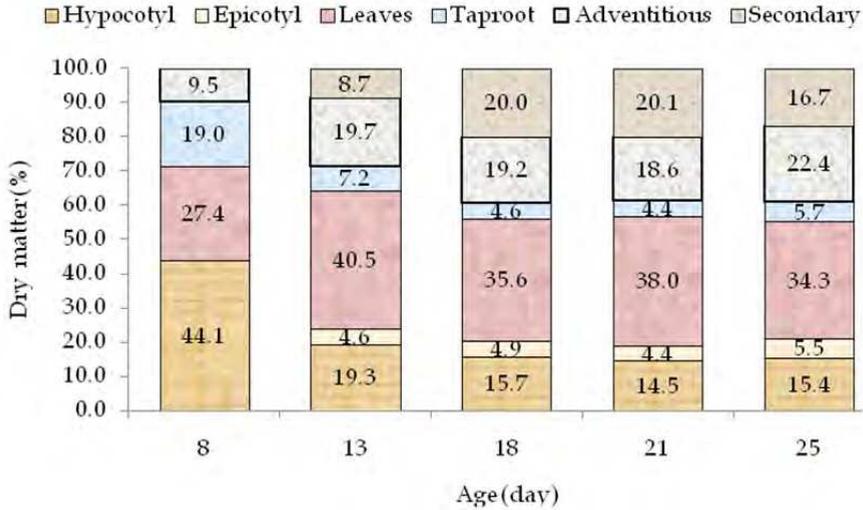


Fig. 7. Distribution of dry matter in bean seedlings developed in light.

In seedlings under darkness was allocated more dry matter to shoot structures (Figure 8), the hypocotyl had higher dry matter, followed the epicotyl and leaves. Unlike seedlings developed in the light, where the leaves accumulated more dry matter, in darkness, it was

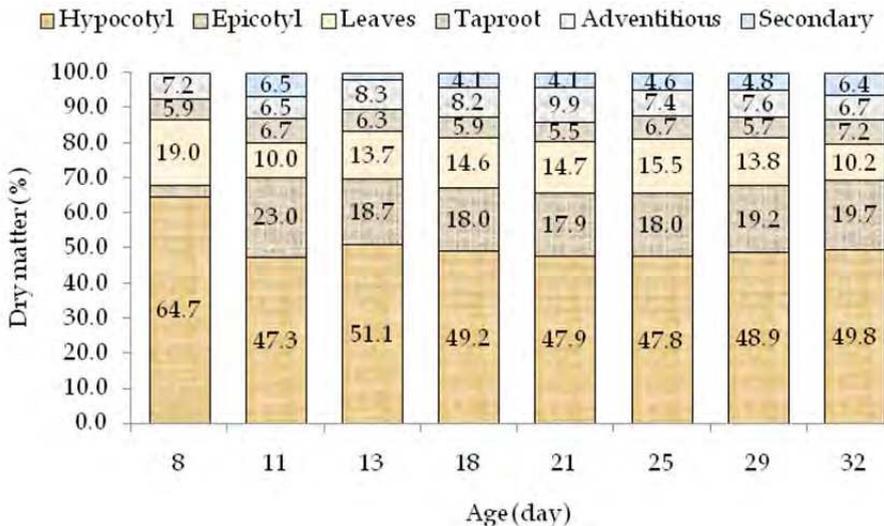


Fig. 8. Distribution of dry matter in bean seedlings developed in darkness.

the hypocotyl. This is evident from the 11 days where the growth is more stable because the 8 days the hypocotyl and the leaves accumulate more dry matter. The distribution of dry matter in roots was more equitable in darkness than in light. However the taproot had less dry matter.

3.7 Water content in shoot structure an roots

The seedlings developed with light, the amount of water upward and downward trends presented in each structure. Hypocotyl water content increased to 8 days, decreased to 13 and increased to 18 days (Table 4), however, the corresponding percentage of water decreased from 8 days. Probably due to their tissue became more fibrous. The epicotyl had a rise in mg of water but a decrease in the percentage of water corresponding. For their part, maintained a rise in leaf water content in both milligrams and percentage. These structures were the most water accumulated at 18 days was the last sampling. It is probably that exist a displacement of water to accumulate as much dry matter.

Age (day)	Hypocotyl		Epicotyl		Leaves	
	mg	%	mg	%	mg	%
2	17.9 ±2.8	86.4 ±0.6	-	-	2.8 ±0.6	83.2 ±3.0
8	525.0 ±95.1	94.9 ±0.9	35.3 ±6.0	77.9 ±1.3	168.3 ±27.5	87.8 ±0.5
13	512.3 ±41.0	92.9 ±0.1	99.7 ±14.6	92.3 ±0.4	676.3 ±32.7	88.7 ±0.3
18	557.3 ±45.3	89.0 ±0.8	128.3 ±10.3	90.6 ±0.5	857.0 ±16.1	93.4 ±0.6

Table 4. Water content in shoot structures of bean seedling developed in light.

In the case of roots, it showed a pattern similar to the structures of the stem with upward and downward trends in milligrams of water in each structure (Table 5). However, the corresponding percentage of water decreased. Adventitious and secondary roots tended to decrease in the percentage of water from 8 to 18 days, however the amount of water recorded in milligrams increased over the same interval. Just as in the structures of the stem, the conduct in the water content in the roots is attributable to tissues become more fibrous and less water.

Age (day)	Taproot		Adventitious		Secondary	
	mg	%	mg	%	mg	%
2	2.3 ±0.5	85.9 ±1.8	-	-	-	-
8	77.8 ±18.6	91.0 ±1.6	93.3 ±28.1	90.4 ±0.9	36.8 ±15.2	95.0 ±2.2
13	114.5 ±43.1	90.5 ±2.5	319.8 ±20.5	90.9 ±0.6	113.5 ±106.4	84.5 ±5.9
18	91.5 ±81.4	84.3 ±7.5	330.0 ±149.5	84.9 ±4.8	155.8 ±109.0	81.9 ±4.4

Table 5. Water content in the roots of bean seedlings developed in light.

In darkness conditions the upward and downward of water content in the shoot structures were more evident than in light. The hypocotyl was the structure that reached the highest water content (2124 mg) at 13 days (Table 6). The epicotyl was the structure with lower water content than the hypocotyl but higher than the leaves, the maximum amount was reached at 18 days. The leaves are structures with less water, it is likely to influence the development precarious that obtain. It is obvious that the seedlings in darkness have higher water content than seedlings developed in the light, but the corresponding percentage was similar, which reached a 90%. In herbaceous plants reported a water content of 80-90% (Kramer, 1983), however, Ehlers and Goss (2003) report between 75 and 95% in stem, leaf and root. Accordingly, the structures of bean seedlings did not affect the percentage of water in the darkness. It may be mentioned that there is a balance in the percentage distribution of water structures in both light and darkness.

Age (day)	Hypocotyl		Epicotyl		Leaves	
	mg	%	mg	%	mg	%
2	30.0 ±2.8	89.7 ±1.3	-	-	-	-
5	670.7 ±86.0	94.9 ±0.3	7.7 ±0.6	88.4 ±0.8	52.0 ±3.0	87.1 ±0.4
8	1981.7 ±59.0	96.2 ±0.1	50.0 ±7.0	92.6 ±1.5	92.3 ±11.0	86.3 ±0.5
13	2124.0 ±87.5	96.7 ±0.3	672.3 ±56.3	96.2 ±0.4	120.4 ±7.0	88.1 ±0.6
18	1817.0 ±201.9	96.4 ±0.5	683.7 ±29.7	96.4 ±0.4	162.0 ±22.8	90.8 ±2.0
22	1104.7 ±173.0	94.8 ±0.3	426.0 ±76.2	95.7 ±0.8	118.0 ±6.7	91.7 ±1.5

Table 6. Water content in structures bean seedlings developed in darkness.

Age (day)	Taproot		Adventitious		Secondary	
	mg	%	mg	%	mg	%
2	8.1 ±2.4	89.6 ±2.1	-	-	-	-
5	87.2 ±9.3	94.4 ±0.3	67.5 ±10.6	94.6 ±0.7	9.3 ±2.1	95.7 ±1.1
8	105.3 ±21.1	94.8 ±0.9	118.4 ±7.0	95.0 ±0.9	50.6 ±9.5	95.4 ±1.0
13	140.0 ±35.3	94.8 ±1.6	164.2 ±21.7	95.0 ±1.1	61.1 ±36.4	91.4 ±6.3
18	59.0 ±47.3	86.2 ±7.8	37.5 ±16.8	79.1 ±3.5	24.6 ±9.8	83.9 ±0.4
22	23.2 ±9.4	81.2 ±2.5	40.3 ±21.0	78.7 ±5.6	16.3 ±5.5	78.7 ±3.9

Table 7. Water content in the roots of bean seedlings developed in darkness.

In the roots appeared similar trends in water content than in the structures of the shoot, with the difference that accumulated less milligrams of water. In all roots reached the highest amount of water at the same time (13 days). Adventitious roots were the more water accumulated (164.2 mg) followed by the taproot (140 mg) (Table 7). The decrease in water content was very dramatic in both milligrams and the percentage of water. This coincided with the decrease in stem dry weight and stability in the roots.

3.8 Distribution and use of nutrients

Considering the weight of the seed represents 100%, it is distributed as follows: 8.9% in shell and 91.15 in the embryo (Figure 9). Of 91.1%, 89.9% corresponds to the cotyledons and 1.2% to the embryonic axis. However, the cotyledons allocated 83.4% to metabolism (metabolic dry matter) and 6.4% as part of its structure (structural dry matter). The embryonic axis use metabolic dry matter available in the cotyledons to resume growth untapped 100% (83.4%), because it spends 32.6% on the respiration. The decrease in dry matter by respiration in darkness conditions has been tested, specifically in leaves (Bathellier et al., 2008). The allocation of dry matter in the seedling is uneven, most are distributed to the shoot than the root. This indicates that the shoot exerts more force on the extraction of nutrients and becomes part of the seedling more demanding but the depletion of reserves in the cotyledons are the first structures to resent the lack of nutrients and tend to lose dry matter. Instead, the roots extract nutrients from the stem to remain. According to Zhang et al. (2010) the seedling hypocotyl elongates significantly by the effect of sucrose stored in the cotyledons, which probably contributes to greater dry matter accumulation in this structure.

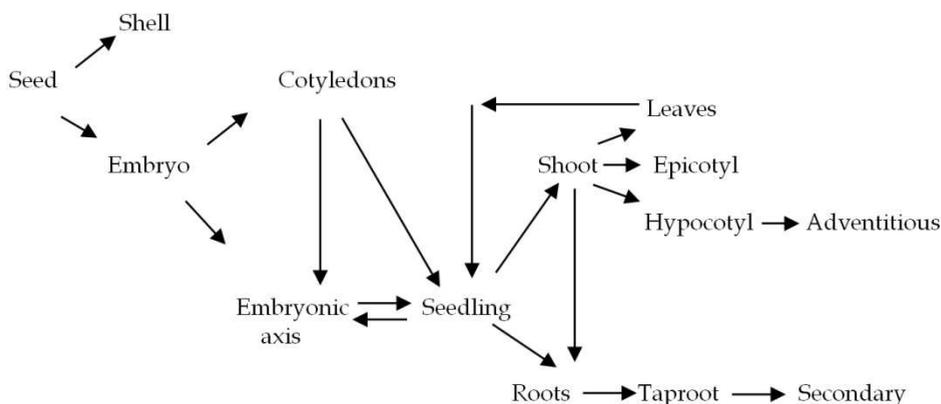


Fig. 9. Allocation and flow of dry matter bean seedlings grown in darkness.

In light conditions, the cotyledons export nutrients to the embryonic axis formed by the stem and root, the seedling until not realize photosynthesis depends on its reserves (Figure 10). However, the cotyledons lose metabolic dry matter and conserved structural dry matter during the development of the seedling so that they become the only structures that die. The embryonic axis uses the nutrients for their development and originates the seedling, in this process is lost dry matter through respiration, which is recovered by the generation of photosynthate through the simple leaves photosynthesis and to a lesser proportion by the cotyledons. In addition to cotyledon, senescence occurs in adventitious roots and secondary

roots but do not die it continue to grow and generate more roots. This process culminates with the release of some individual roots or only in the degeneration of the epidermis and barking, the latter feature has been observed in grape (Mapfumo and Aspinall, 1994). After the death of the cotyledons, photosynthates demanding by the structures of the stem and roots are provided by simple leaves that realize photosynthesis. These structures become the main source of nutrients to reach senescence (Yin and Watson, 1990). Finally, establishing the flow of nutrients from leaves to the seedling, which distributes the nutrients in the stem and root, root turn supplies water to the seedling.

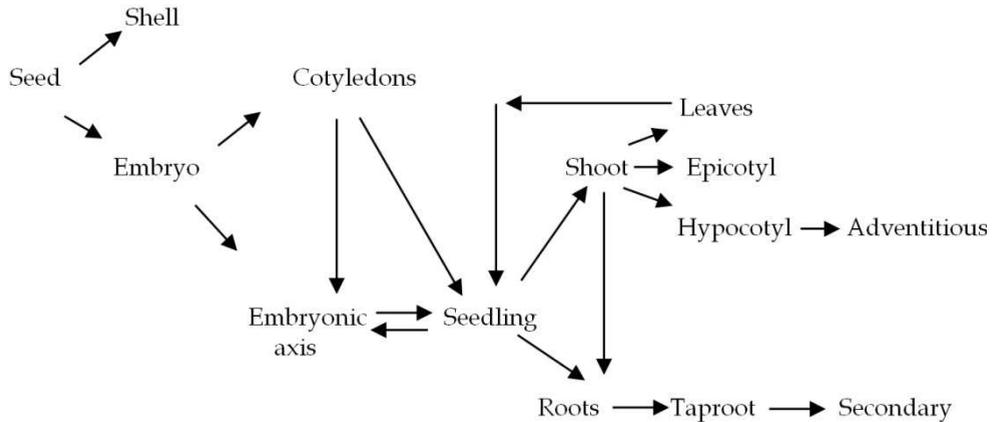


Fig. 10. Flow of nutrients in bean seedlings developed in darkness.

3.9 Relationship of dry matter and seedling senescence

During the development of seedlings in the darkness all the structures of shoot and root dry matter accumulated except for cotyledons. These structures are stored nutrients which are used in the growth of seedlings. As a result, these organs show a decrease in dry weight as nutrients export, although some of the dry weight decrease is attributed to respiration. When the cotyledons die deplete its reserves, the event coincides with the maximum dry matter accumulation in the seedling.

Seedling senescence starts at the tips of the simple leaves (not counting the cotyledons), five days after maximum dry matter accumulation, specifically in the shoot, when the roots reach their maximum dry weight (Díaz-Ruiz et al., 1999). Likewise, adventitious and secondary maintained a slight increase in dry matter. This indicates that at the beginning of senescence, the leaves provide nutrients as well as the epicotyl and hypocotyl to the roots (Figure 11). The decrease in dry matter in the adventitious roots was noted after the start of senescence at the tips of both of them as secondary root. Adventitious roots before the secondary present the senescence as a result of the death of the hypocotyl that becomes their main source of nutrients after the cotyledons die. The main or primary root decreased their dry weight for the following reasons: nutrient intake by respiration, the existence of detachment of the cortex in the apical region of the root that cause death secondary root located in that region and export nutrients to the secondary roots and their use for maintenance of herself. As the nutrient reserves were decreasing, seedling allocated less amount of nutrients to the roots to be zero allocation, so the secondary roots

are affected and die first than taproot (Figure 11). According to Klepper (1991), the way in which grows the stem is different from the root but the relationship between them is undeniable.

Initially, the cotyledons exported nutrients to the shoot and root first, the root supplies to shoot the extracted soil water. At death the cotyledons, shoot sends nutrients to the root, thus kept alive longer than the shoot, which die for lack of nutrient supply. In the shoot, hypocotyl dies last and roots are the taproot. The allocation of more dry matter to the shoot is growing faster than the root and has increased demand for nutrients. Because they do not perform photosynthesis, shoot structures supplement for a short period of time the demand for nutrients that makes the root, this allows to extend the time of accumulation of dry matter. Thus, by failing to supply photosynthate to shoot dies first than the root. In general, all structures of the shoot and roots, senescence started after reaching its maximum dry matter accumulation

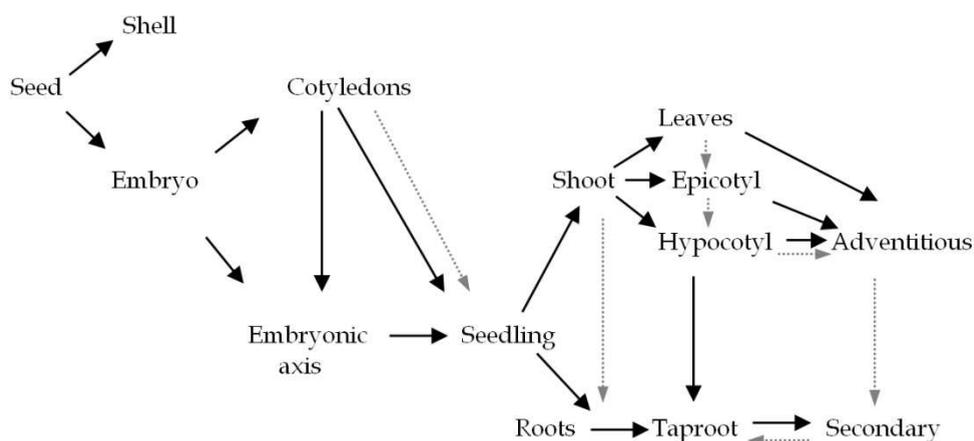


Fig. 11. Nutrient flow (→) and progress of senescence (····→) in bean seedlings developed in darkness.

4. Conclusions

The seedlings developed in light use nutrients from the cotyledons and the photosynthate formed by photosynthesis by the leaves. In darkness the seedlings grow with nutrients from the cotyledons only. Thus, seedlings become autotrophic light and dark heterotrophic only because they do not perform photosynthesis.

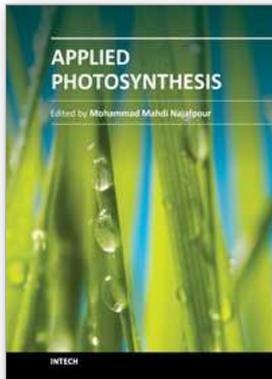
The dry matter accumulation in bean seedlings developed in darkness and under light is different because in each condition, the amount of nutrients available to seedlings is different. Seedlings show marked differences in morphology and proportions of distribution and allocation of dry matter in the structures shoot and root formed.

The dry matter decreases in the cotyledons because provide nutrients to the shoot and root, which increases its content of dry matter. Shoot accumulates more dry matter than the root. The senescence of the cotyledons is shown in light and darkness conditions. In light conditions the leaves are the structures that accumulate more dry matter and in darkness is the hypocotyl.

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Photosynthesis is one of the most important reactions on Earth, and it is a scientific field that is intrinsically interdisciplinary, with many research groups examining it. This book is aimed at providing applied aspects of photosynthesis. Different research groups have collected their valuable results from the study of this interesting process. In this book, there are two sections: Fundamental and Applied aspects. All sections have been written by experts in their fields. The book chapters present different and new subjects, from photosynthetic inhibitors, to interaction between flowering initiation and photosynthesis.

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