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Aroids and Water Relations: An Overview

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Abstract

Major edible aroids, elephant foot yam, taro and tannia constitute staple food for the low income group and tribal people in India. As such their yield potential has not been well realized. Limited studies have been conducted on the scientific water management, especially water relations and water requirement of aroids. These crops are mostly rainfed. However, they are known to have high water requirement due to great transpiration loss and long duration. Their large leaves are extensive transpiring surfaces through which large quantities of water are transpired. Effects of water deficit stress during various phases of these crops are reported to affect the productivity, particularly, if stress occurs during the tuber bulking phase rather than tuber initiation or maturation phases. Elephant foot yam produces large corms when water supply is adequate. Continuous flooding adversely affects the performance. The initiation of sprouts from seed corms to initiation of senescence is decided by the availability of soil moisture. Taro comes up well in moist environments. Tuber bulking phase has been considered as the most critical phase in taro. Tannia is relatively more tolerant to dry conditions and is sensitive to water-logging, but performs better under irrigation especially when rainfall is irregular. Thus water can be considered as the most critical input in aroid cultivation. Limited studies conducted on water management and water relations of major edible aroids are reviewed here.

Key words: Aroids, elephant foot yam, taro, tannia, water requirement, water deficit stress, growth characteristics, corm yield

Introduction

Aroids form an important group of tropical tuber crops, which are cultivated and consumed as staple or subsistence food in the tropical climates of Asia, Africa, Latin America and the Pacific (Onwueme and Charles, 1994). Aroids are a rich and cheap source of energy, minerals and vitamins. They are also used in indigenous medicinal preparations for various ailments. High water requirement and ability to tolerate partial shade are common features of aroids. Edible aroids are herbaceous plants with enlarged underground storage organs, such as corms and cormels. The major edible aroids that are cultivated and used as food in various parts of tropics, including India are: Elephant foot yam (*Amorphophallus paeoniifolius* (Dennst.) Nicolson), taro (*Colocasia esculenta* (L.) Schott.) and tannia (*Xanthosoma sagittifolium* (L.) Schott.). In addition, *Amorphophallus konjac* which is cultivated for extraction of glucomannan, konjac flour, konjac gum etc. and swamp taro (*Cyrtosperma markusii* Schott.), are also cultivated to a limited extent. Besides, there are several other aroids which are edible (Unnikrishnan et al., 2012).

Aroids are known for their relatively high water requirement. They produce large leaves and transpiration is directly related to leaf area. Their large leaves are extensive transpiring surfaces through which large quantities of water are transpired. Among the edible aroids, tannia is mostly cultivated as rainfed crop in Kerala (Suja and Nayar, 1996) whereas taro and elephant foot yam are grown both under irrigated and rainfed conditions. For better productivity, evenly distributed rainfall throughout the growth period is essential. Wherever rainfall is scanty, supplementary irrigation has to be provided during dry spell to ensure higher yields (Nayar, 1989).

This paper documents the available information on growth characteristics, effect of moisture deficit stress and water requirement of major aroids viz., elephant foot yam, taro and tannia.

Elephant foot yam

Elephant foot yam (*Amorphophallus paeoniifolius* (Dennst.) Nicolson) thrives well in warm humid climate with a mean temperature of 30-35°C during the crop growth period. It is cultivated in areas with well distributed rainfall of 1500-1800 mm over 6-8 months. In Kerala, the crop is mostly cultivated under rainfed conditions by planting during February-March and harvesting in January. In Andhra Pradesh, as *kharif* (rainfed) crop, elephant foot yam is planted during May-June and harvested during January-February. It is also cultivated as a *rabi* crop by planting in November-December and harvesting during April-May (Narasimha Murthy et al., 2008). In Bihar and Uttar Pradesh, the crop is cultivated under rainfed conditions by planting during February-April and harvesting in January (Singh et al., 2008a; Sengupta et al., 2008). In Tamil Nadu, the crop is planted during April-May under irrigation and harvested in January-February (Sarswathi et al., 2008). In Gujarat, the crop is planted under irrigated conditions between middle of March and June and harvested during middle of November to January (Patel et al., 2008). In Odisha, under rainfed conditions, the crop is planted with the onset of monsoon in May-June and harvested in January. Under irrigated conditions, elephant foot yam is planted in mid-March in Odisha (Naskar et al., 2008). The crop planted in March obviously gives better yield as compared to June planting. A light irrigation should be provided immediately after planting. Depending upon the soil moisture availability, irrigation should be given at regular intervals till the onset of monsoon under such conditions (Misra et al., 2001). Studies conducted at CTCRI indicated that when the crop is planted during February with irrigation, sprouting starts early. Within 45 days, 77% of corms sprouted with drip irrigation whereas only 22% of corms sprouted without irrigation (CTCRI, 2012). Elephant foot yam grows well in medium to light soils with adequate amounts of organic matter because they prefer well aerated soils. The crop can tolerate temporary flooding, but anaerobic water logging causes corm rot (Ravi et al., 2011).

Growth characteristics

The new sprout emerges from the corm pieces or full corm depending on the dormancy status of planting material which varies from 3 to 4 months. Further development of new shoots is completed within 30 days. During a growing season, up to 12 leaves are produced successively. As such, more than two leaves coexist at the same time (Ravi et al., 2011). The number of stomata in the lower epidermis increased from 10.22 per unit area at 50 days after planting (DAP) to 17.78 per unit area at 150 DAP (Gopi et al., 2008). The leaf area index (LAI) increased with time and reached maximum (6.1) at 120 DAP at a planting density of 14,420 plants per ha (Das et al., 1997). The increase in number of stomata and leaf area between 4 and 6 months of crop growth period indicate more transpiration loss of water from the crop canopy which eventually increases water requirement during this period. Canopy spread varied between 70.2 and 143.8 cm (Ravindran and Kabeerathumma, 1991; Sen and Das, 1991; Goswami and Sen, 1992; James George and Nair, 1993, AICRP, 2007; 2008; 2009) under different agro-climatic conditions. Increase in size of seed corms used for planting resulted in more canopy spread of plants (Bhagavan et al., 2008). When corm size for planting increased from 50 g to 200 g, there was an increase of canopy spread with maximum of 74.4 cm (200 g) followed by 68.87 cm (175 g) and 66.5 cm (150 g) (Singh et al., 2008b). Increase in canopy spread also enhanced transpiration loss and water requirement of the crop. However, smaller corms planted at a closer spacing also may have more exposed canopy leading to more transpiration loss and total requirement of water. Canopy spread varies with different varieties also. The variety Gajendra planted during October using 500 g corms under irrigated conditions had a mean canopy spread of 155.83 cm and a LAI of 1.17, whereas that planted during April under rainfed conditions resulted in a mean canopy spread of 68.76 cm and a LAI of 0.59. Sree Padma had a mean canopy spread of 73.67 cm and 78.81 cm and a LAI of 0.49 and 0.82 when planted during October and April respectively. The variety Sree Athira produced 66.93 cm and 88.68 cm canopy spread and LAI of 0.61 and 0.82 respectively when planted during October and April respectively (CTCRI, 2011).

Detailed investigations are required to study the correlation between corm size, canopy spread and water requirement of the crop.

Application of growth regulators viz., triadimefon, paclobutrazole and propiconazole through soil drenching increased total root length, dry weight of whole plant, leaf thickness, net photosynthetic rate and water use efficiency by 56.81 to 87. 9% as compared to untreated control plants. In contrast, total leaf area, transpiration rate and stomatal conductance decreased (Gopi et al., 2005; 2008; 2009).

Roots grow out from the surface of newly developing daughter corms at the base of petiole (pseudostem) with leaf emergence. These roots extend horizontally and are densely distributed at a shallow depth of top 15-30 cm of soil. Roots grow more than one metre in length under adequate soil moisture conditions and rains and are known as "rain roots". Under dry soil conditions, the root length decreases to less than 30 cm (Ravi et al., 2011). A new daughter corm is formed in the region between the petiole and seed corm when a sprout grows from the corm. It continuously grows and bulks as long as there is adequate moisture in the soil. Corm growth rate increases steadily between 1 and 5-6 months after planting. Maximum bulking rate was observed during fifth or sixth month (Mukhopadhayay and Sen, 1986; Nair et al., 1991). Under rainfed conditions, even with constant size of planting material, corms harvested from a particular field showed gradient sizes. Nevertheless, the proportion of gradient sizes may narrow under the best management and soil conditions (Ravi et al., 2011). Hence, proper water management deserves special mention in this context.

Effect of water deficit stress

Limited studies have been conducted on the response of elephant foot yam to water deficit stress. Santosa et al. (2004) tried different irrigation schedules at 1, 3, 5, 7 and 15 days intervals, when the buds became visible in elephant foot yam. Frequency of irrigation affected the number and size of leaves, corm size, cormel number and root growth, while longer intervals (>15 days) between irrigation restricted leaf growth and yield. Growth of plants did not show any abnormality when the plants were irrigated at 1, 3 or 5 days intervals. However, infrequent irrigation reduced yield and forced the corms to enter into dormancy after leaf senescence. Frequent irrigation produced larger leaves with more leaf area and leaf area duration compared to less frequent irrigation. A decrease in the dry mass of seed corms was more evident with frequent irrigation, whereas reserved carbohydrates in seed corms were not easily metabolized under a limited water supply when irrigated at longer intervals. The high ratios of decrease in dry mass of seed corms to original mass under frequent irrigation could be ascribed to the fact that the soil water availability not only affected the utilization of carbohydrates in seed corms, but also the production and translocation of photo-assimilates into daughter corms (Sugiyama and Santosa, 2008). The roots dried earlier than usual when soil water content decreased to less than 40% of field capacity and the crop tolerated water deficit stress conditions for about 30-60 days, but prolonged stress affected corm yield (Santosa et al., 2004). Water deficit stress during 4-6 months period significantly affected growth and productivity of elephant foot yam and initial establishment. Crop growth period between 4 and 6 months are the critical periods which require adequate soil moisture for achieving more corm yield (Ravi et al., 2013). These results suggest that although elephant foot yam tolerates soil water deficit stress, it should be avoided to ensure high corm yield.

Water requirement

Exposing seed corms to running water for six days resulted in greater sprouting than control. However, exposing seed corms to water for more than six days led to a lower percentage of sprouting (Rajendran and Hrishi, 1976). Elephant foot yam produces large corms when water supply is adequate. About 1000-1500 mm of rainfall per year is optimum for the crop. Changuler and Khot (1963) recommended 9 to 10 irrigations during a growing season for elephant foot yam. Philip and Nair (1994) found that under Kerala (India) conditions, irrigation during dry spell of crop growth period was uneconomical though it had significant positive effects on the growth of elephant foot yam. In Tamil Nadu, it is raised by providing weekly irrigations (Srinivas and Ramanathan, 2005). Soil moisture conservation methods like mulching induced higher percentage of early sprouting, greater canopy spread, plant height, greater mean corm weight and corm yield (Mohankumar et al., 1973). Soil moisture status does not influence sprouting, but further development of new leaf depends on adequate soil moisture (Ravi et al., 2009). Elephant foot yam produces large corms and yields more when the water supply is adequate (AICRP, 2008). The crop enters dormancy earlier than usual when the rainy season is shorter than four months and supplementary irrigation is necessary for high productivity under the same conditions.

In India, commercial growers plant the crop by the end of March or beginning of April with protective irrigation. Farmers give more than 20 irrigations during a period of six months, apart from rainfall. Generally, farmers follow flood irrigation. In each irrigation, they provide 4-5 cm of water which is not uniformly distributed in the field (Nedunchezhiyan et al., 2008). As elephant foot yam is a widely spaced crop (90 x 90 cm), lot of water is wasted by flood irrigation. Drip irrigation is advantageous for elephant foot yam (Nedunchezhiyan et al. 2008). There was 40% yield increase under drip irrigation than under flood irrigation. The corm yield was greater under drip irrigation @ 60% of cumulative pan evaporation (CPE) daily for the first 15 days and then on alternate days for the next 15 days, @ 80% of CPE between 2 and 6 months and then @ 60% of CPE between 7 and 8 months. However, maximum corm yield was obtained under 100% recommended dose of fertilizers along with flood irrigation and the yield was on par with drip irrigation @ 100% CPE throughout the crop growth period. Corm yield was significantly reduced with irrigation @ 80% of CPE and 60% of CPE (AICRP, 2009).

In another study, drip irrigation @ 100% CPE on alternate days along with application of 120 kg each of N and K per hectare resulted in maximum corm yield (35.1 t ha^{-1}) followed by drip irrigation @ 80% CPE (34.4 t ha^{-1}). Highest water use efficiency was observed with drip irrigation @ 80% CPE (CTCRI, 2011). Across various agro-climatic regions of India, irrigation @100% CPE with 100% recommended dose of fertilizers promoted growth and yield parameters significantly in elephant foot yam (James George et al., 2012). However, nutrient use efficiency was not found enhanced in these studies under fertigation. The cost of cultivation, corm yield and gross income of elephant foot yam cultivation were greater under irrigated production system than under rainfed production system (Srinivas and Ramanathan, 2005). These studies revealed that irrigation increases the productivity of elephant foot yam, though prolonged water logging is harmful to the crop.

Taro

Taro (*Colocasia esculenta* (L.) Schott.) is one of the important tuber crops of the world from antiquity. Presently it provides the main staple food of many people in the humid tropics and sub tropics. It is one of the third important dietary staple food for low income consumer (Kurup, 1992). Taro acts as a buffer crop during the shortage of other staple food. Its ability to produce a crop under extremes of water regimes from upland to shady moist places or flooded conditions makes it a valuable crop for selective development programmes (Chadha, 1993). The growth and development of taro under upland conditions is likely to be similar to that of wet land conditions (Narzary and Rajendran, 1999).

There are mainly two groups of taro: the eddoe type, which has a relatively small central corm surrounded by large well developed cormels (*Colocasia esculenta* var. *antiquorum*) and the dasheen type, which has a large central corm and numerous small cormels arising from its surface (*Colocasia esculenta* var. *esculenta*).

Growth characteristics

Taro is vegetatively propagated using small corms, corm pieces or cormels and the plants have indeterminate growth habit. It can grow as long as soil moisture is available. In taro, the time of initiation of corm/cormels, corm growth and the total growth period vary widely depending upon the cultivar and the agro-climatic conditions, particularly soil moisture (Ravi, 2000). Studies by Reynold and Netran (1977) revealed that there are three growth phases in taro. First phase is from 1 to 4-5 months, a period of rapid development of root and shoot along with tuber initiation. The second phase is from 4-5 to 6 months with maximum root and shoot growth and tuber development. The third phase is from 6 to 9 or 6 to 11 months, when senescence with reduced rate of corm enlargement occurs. Studies by Sivan (1979) under dry land conditions revealed that during the first and second weeks, roots were formed and the first leaf was produced. Ching (1970) and Plucknett and Pena (1971) found that in taro grown under highly fertile and irrigated conditions, the leaf area increased from planting to 6th month and then declined slowly between 12 and 15 months. Under this condition rapid corm development was found to commence between 3 and 5 months and continued until 12-15 months. It appears that under less fertile, dry land conditions, corm development commences early and crop growth period is shortened due to lack of moisture and nutrients.

Wilson (1984) described the leaf growth pattern of taro under upland/rainfed conditions. Accordingly rapid leaf growth began 1.5 to 2 months after planting and LAI reached maximum between 3 and 5 months. However, taro cultivars produced significant corm yield in 5 months growth period under upland rainfed conditions (Ravi and Chowdhury, 1996). In these cultivars, the leaf area increased continuously up to 4 months and decreased at 6th month due to decline in soil moisture because of decrease in rainfall. Chowdhury et al. (2010) evaluated four cultivars of taro, BCST-4, BCST-15, BCST-23 and a local collection, Erasma local and one cormel forming taro cultivar, Cooch Bihar, under swampy conditions in low lying areas. Maintenance of greater leaf area, leaf chlorophyll, root nitrate reductase activity in post submergence period suggested the suitability of BCST-15 for cultivation in low lying flood prone areas. Taro has a shallow root system and majority of the roots are confined to a lateral spread of 40 cm and depth of 9 cm in the soil (Mohankumar and Sadanandan, 1990). Decrease in soil moisture drastically reduced leaf area, leaf longevity, stomatal opening and dry matter production (Ravi and Chowdhury, 1993a; Ravi and Chowdhury, 1991) and corm yield in taro (Ravi and Chowdhury, 1996). Hence water is reported to be a critical input throughout the growth period of taro.

Effect of water deficit stress

Taro grows and yields better in moist environments, but can be cultivated under a wide range of moisture regimes (Wilson, 1984). However, under tropical conditions, the crop is often subjected to unfavorable growing conditions, due to water deficit stress. In general, the eddoes are hardier than the dasheens and can be grown in rainfed conditions in less fertile soils (Kay, 1987). Among the two types of taro, the eddoe type is considered to be tolerant to drought conditions (Kay, 1973). Ravi and Chowdhury (1991) observed that 25% of soil moisture saturation adversely affected the growth and corm yield of eddoe type of taro. Reynold and Netran (1977) observed a close relationship between the rainfall received during 4th, 5th and 6th month period, which coincided with tuber bulking in taro in Western Samoa. Hence, tuber bulking stage has been considered as the most critical period of water deficit stress in taro.

Under upland cultivation in Fiji, especially when grown as a rainfed crop, the cormels produced are generally below marketable size and are useful only as planting materials for the next year crop. Hence, in this situation, cultivars which produce only one or two cormels of reasonable size are more ideal (Sivan, 1977). However, in India, many taro varieties can produce cormels of marketable size under rainfed conditions. On the other hand, in flooded conditions, the cormels contribute significantly to the marketable yield (Pena, 1967; Sivan, 1979). Ezumah and Plucknett (1977) also reported that in irrigated crop much of the yield brought about by increased cormel yield was due to additional moisture. Tuber differentiation in taro under upland conditions starts early and corm formation begins when the plant is about two months old (Sivan, 1979). Under moisture deficit stress, taro showed significant reduction in leaf production, while tannia showed only a slight reduction in leaf number. Leaf area and plant height of taro declined steeply under water deficit stress (Pandales, 1979).

Ghuman and Lal (1984) studied the physiological response of taro to moisture regimes by altering the water table depths in lysimeter. They found that the leaf water potential increased from -6.6 to -5.1 bars in the cultivar, TCE 23, by lowering the water table from 15 to 50 cm with no effect on stomatal diffusive resistance. Taro plants grown under 25% soil moisture saturation showed greater reduction in relative water content (RWC), total chlorophyll, sugar content and membrane stability in leaves. Accumulation of greater amount of proline in leaves under 25% soil moisture than under 50% and 100% soil moisture saturation indicated that plants under 25% soil moisture have undergone maximum stress than those under 50% and 100% soil moisture saturation (Ravi and Chowdhury 1991; 1993b). Taro plants grown under 25% of soil moisture saturation showed greater reduction in leaf area, growth and yield as well as greater stomatal closure than those grown under 50 and 100% of soil moisture saturation. Therefore, 50% soil moisture saturation can be considered as the critical level below which taro crop may experience water deficit stress and yield reduction (Ravi and Chowdhury, 1997).

Ezumah and Plucknett (1977) studied the performance of taro irrigated with the same quantity of water through sprinkler, flood and furrow irrigation. Under sprinkler irrigation, corm yield at 10 months increased with increasing LAI up to 2.8 and declined with further increase in LAI, whereas under flooding there was no distinct optimum LAI, while corm yield increased with LAI up to 3.0 and remained constant thereafter. With furrow irrigation, the optimum LAI ranged from 4.5 to 6.5 for maximum corm yield.

Warm stagnant water resulted in a low oxygen content and caused basal rotting of taro (Onwueme, 1999; Jeri and Berry, 2000). Drought tolerance of taro is a major objective in breeding programmes. Sahoo et al. (2006) evaluated a taro hybrid along with its parents for water deficit stress tolerance under polyethylene glycol mediated osmotic stress with minimum yield reduction. Based on a comparison of water conservation tillage methods and irrigation, Manyatsi et al. (2011) concluded that growth parameters and yield of taro were maximum under irrigation under flat tillage method. Growth parameters and yield of taro decreased in the order by tied-ridges, ridges, half moon and under rainfed flat tillage conditions.

In a green house study, the initial period of dry matter loss of planted corms during establishment of taro could be minimized with adequate water and nutrients (Jacobs and Clarke, 1993). Taro should be provided with sufficient water for maximum leaf production during the growth period. It is essential to maintain soil moisture at field capacity which when falls, should be supplemented with irrigation. However, under rainfed situations, a dry spell should be supplemented by irrigation otherwise it would accelerate the senescence of leaves. When cultivated during summer, taro requires frequent irrigation at 5 days interval (Ezumah and Plucknett, 1977).

Water requirement

Taro is primarily adapted to moist environments, but can be grown under a wide range of conditions, ranging from low land paddy culture to upland conditions under irrigation. An annual rainfall of approximately 250 cm is considered optimum, however, they can be grown in upland areas where the rainfall is about 175 cm provided it is evenly distributed throughout the growing period. In upland culture of taro, it is important to ensure a continuous availability of water. Where rainfall is irregular, irrigation facilities must be provided. Either furrow irrigation or sprinkler irrigation may be practiced (Onwueme and Charles, 1994). When grown under upland areas with less than 175 cm of rainfall, irrigation is necessary to provide sufficient water for vegetative growth and leaf development and the use of furrow and sprinkler has proved satisfactory (FAO, 2005). High rainfall is needed during the first 20 weeks growth period corresponding to the period of maximum leaf development. Thereafter, drier conditions can be tolerated until harvest (Lebot, 2009).

In Egypt, the crop is irrigated at biweekly intervals for the first 6-8 weeks, then weekly for the next 4 weeks and thereafter every 4-5 days until near harvest. Dasheen corms grown under erratic moisture conditions showed peculiar dumbbell like shapes reflecting constrictions in growth during dry periods. Under water deficit stress, eddoe type taro produced few cormels (Fujimoto, 2009).

Apart from rice and lotus, taro is one of the few crops in the world that can be grown under flooded conditions. The large air spaces in the petiole permit the submerged parts to maintain gaseous exchange with the atmosphere (Sunell and Arditti, 1983). Also, it is important that the water in which taro grows remains cool and continuously flowing, so that it can have maximum dissolved oxygen. Taro leaves exude water at the tip of their laminae through guttation and the amount of water exuded in field conditions varies from 10 ml to 23 ml per night. Under upland conditions, water requirement for taro was larger (500-800 g g^{-1}) during early and later growth period than during the intermediate growth period (200-300 g g^{-1}). For the production of 1g dry matter, taro required 308 to 486 g water (Kato et al., 1969; Mandal 1993). Ezumah and Plucknett (1977) compared the effect of different irrigation methods on taro by supplying equal amounts of water through sprinkler, furrow and continuous flooding and found that flood irrigation was more effective in realizing higher yield. The greater yield associated with flooding have been attributed to a greater ability to produce suckers and to a greater leaf area. Here, the rate of leaf senescence was also lower.

Drip irrigation in taro fields resulted in less loss of water to lower soil layers, while growth and yield of taro was maximum with application of 2 mm water per day (Muto et al., 1980). Pena and Melchlor (1984) conducted experiments to determine the effects of six different rates of water flow (2,80,470 l ha^{-1} day^{-1} to 9,81,640 l ha^{-1} day^{-1}) and six depth of flowing (0-20 cm) on the yield components of taro. Water use efficiency calculated on the basis of litres of water needed to produce a kilogram of taro was 800 l kg^{-1} for the lowest rate of water flow and 2790 l kg^{-1} for the highest rate of water flow. Yields of low land taro decreased as depth of flooding increased from 0 to 20 cm. Optimum depth of flooding in low land taro appeared to be 4-8 cm as this was sufficient to keep the weeds under control without causing severe yield loss. Surface and sub surface irrigation with 20 mm of water, when the soil pF reached 2.5 at 10 cm depth increased total yields of main corm and cormels by 90 and 72% respectively (Kudo, 1987).

It is possible to estimate the evapotranspiration (ET) for determining irrigation schedule for taro or for water resource planning and management in accordance with available standard pan evaporation (SPE) data and the ET/SPE ratio. The ET/SPE ratio between 0.9 and 1.0 was appropriate when LAI was less than 1.0 before canopy closure and between 0.73 and 0.75 when LAI was greater than1.0 after canopy closure (Shih et al., 1988).

Upland taro production had a lower water requirement of 4000 to 9000 gallons $acre^{-1}$ day^{-1} and could be grown in areas similar to that of other crops (Uchida et al., 2008). Nevertheless, upland taro yield tends to be inferior to that of low land taro. Studies conducted by Jensen et al. (2011) showed that cormel yields increased with increase in irrigation. Irrigating taro at 150% ET0 maximized yield under lowland conditions. Irrigation up to 250% ET0 did not result in yields comparable to flooded conditions. In addition, the potential to predict corm yield based on its relationship to per cent ET0 replaced can assist in crop modeling and irrigation scheduling to maximize water use efficiency of taro. Thus, taro is a crop well adapted to moist environments. Adequate moisture is essential for maximizing growth and potential yield of taro. Starting from sprouting, throughout the vegetative phase, tuber bulking phase as well as initiation of senescence, ie., the crop duration is decided by the moisture availability in the soil. Thus, water is a critical input in taro cultivation.

Tannia

Tannia, (*Xanthosoma sagittifolium* (L.) Schott.) is one of the six most important root and tuber crops grown worldwide attaining importance as energy foods (Onwueme, 1978). Tannia is mainly cultivated by small scale farmers in Asia, Africa and Latin America (Wilson, 1984). The corms, cormels and leaves of tannia are an important source of carbohydrates, vitamins and minerals for human nutrition and animal feed (Nyochemberg and Garten, 1998). In India, tannia is grown in Maharashtra, Kerala, parts of Tamil Nadu, Kerala, West Bengal and North Eastern states (Misra et al., 2005).

Growth characteristics

The general growth pattern of tannia appears to be similar to that of taro (Igbokwe et al., 1984; Wilson, 1984). Igbokwe et al. (1984) recognised three major phases of growth in tannia. The first phase lasts for 8 weeks from planting and sprouting starts after 2 weeks. This phase extends up to 8 weeks and is characterized by the emergence and growth of roots and leaves. The second phase lasts for about 16 weeks from 8th to 20th week of growth. Rapid production and growth of leaves occurs between 16 and 20 weeks. New corms develop very rapidly after 10 weeks until 22 to 24 weeks. The decline in leaf production commences at about 20 weeks and the production of corms and cormels increases slightly during 24-26 weeks. Wilson (1984) found that the highest leaf growth in tannia occurred between 4.5 and 6 months of growth. Maximum leaf dry weight and LAI occurred between 5.5 and 6.5 months and the plant height was maximum at 7th month. After 7th month, leaf dry weight and LAI and plant height declined until harvest at 10th month. Accumulation of dry matter in the central corm began at about 3 months after planting and corm weight increased rapidly until 7th month.

Effect of water deficit stress

Tannia requires well drained soil for optimum growth and cannot withstand water logging. Among the aroids, tannia is relatively more tolerant to dry conditions, but performs better under irrigation, especially when rainfall is irregular (Onwueme and Charles, 1994). A severe reduction in yield was observed in tannia if the depth of water table was reduced from 0 to 15 cm. According to

Silva and Irizarry (1980) the free water table must be kept at 45 cm below soil surface to get high yields from tannia. Tannia produces highest yield under shade and adequate water supply and when water deficit stress conditions prevails, only the main corms grew, while the growth of cormels was negligible (Caesar, 1980). As a result of the increased development of above ground plant organs under shade, the plant can withstand water deficit stress conditions but with a low yield of edible tubers. Tannia cormel yields of 9.9, 11.7 and 16.6 t ha^{-1} at water table levels of 15, 30 and 45 cm below the soil surface respectively were obtained in a study involving different depths of free water tables in Puerto Rico (Silva, 1980).

Planting season affects the properties of starch in tannia. Those planted in summer had greater total starch and amylose contents and larger average granular size of starch than those planted in winter and spring seasons. Difference might be due to variation in total rainfall during fourth to the tenth month of the growth period (Ting-Jang Lu et al., 2005).

Water requirement

Tannia are plants of tropical rain forest region which require copious rainfall and adequate soil moisture (Lopez et al., 1995). The crop is suited to high rainfall areas receiving an annual precipitation of 140-200 cm but it can also grow well with an annual rainfall as low as 100 cm, provided it is evenly distributed (Ramesh et al., 2007). Tannia can be grown under upland conditions with irrigation and certain early maturing cultivars can be grown without irrigation in comparatively dry situations.

In East Central Puerto Rico, average yields of tannia cultivars increased by 37% under irrigation (Irizarry et al., 1977). In Puerto Rico, however tannia yields always increased with high irrigation, even though total rainfall during the growth cycle exceeded standard pan evaporation (Snyder and Lugo, 1980). Goenaga (1994a) reported yield increases with irrigation up to 132% of evapotranspiration parallel to an increased nutrient uptake. Experiments revealed that furrow irrigation usually resulted in better growth and yield (Onwueme and Charles, 1994).

In Puerto Rico, Goenaga (1994b) studied the partitioning of dry matter in tannia, irrigated based on class A pan factor ranging from 0.33 to 1.32 with increments of 0.33. Dry matter partitioning to cormels were greater in plants replenished with 0.33 and 0.66 of water lost through evaporation than in other treatments.

So, available literature reveals that, though growth habits of tannia is similar to taro, it is comparatively drought tolerant and sensitive to water logging. However, supplemental irrigation is reported to enhance tannia cormel yield under rainfed situations. Systematic studies are yet to be taken up on water management and the effects of water stress on this crop.

Conclusion

Tuber crops are mostly cultivated under rainfed conditions. Research on water management of tuber crops has been less focussed, especially in India. Only scanty research has been carried out on the role of water in aroid cultivation. Few studies on the effects of water deficit stress on growth of aroids, the beneficial effects of adequate soil moisture on growth, dry matter partitioning and tuber yield are documented.

Water plays an important role at critical periods of crop growth. Any water deficit stress occurring during the critical phases would adversely affect the ultimate performance of crops. Anticipating the climate change effects and erratic distribution of rainfall, sustainable water management strategies ensuring higher yields in traditional areas should be developed for extending the cultivation to non-traditional areas, enabling off season cultivation and increasing the productivity to meet the perennial and increasing demand of tuber crops for domestic and industrial uses.

The scarcity of irrigation water for crop production further necessitates efficient water conservation and management practices for sustainable food production even in high rainfall areas (Panda et al., 2004). In addition, judicious and sustainable management of water and proper irrigation scheduling is necessary to produce optimum yields. Hence, the possibilities of suitable water saving techniques along with studies on water requirement of crops and suitable irrigation scheduling becomes imperative. Because aroids are mostly of longer duration, supplemental irrigation during dry spell also becomes essential to produce a better crop in high rainfall areas especially in the context of climate change. Moreover, when cultivated during summer season, these crops invariably require irrigation. So, a better understanding of physiology, phenological phases, water requirement during critical growth periods, etc. is essential for judicious use of water. In view of limited availability of water for cultivation in near future, detailed studies on optimum water requirements-crop wise, location wise and season wise are also required for exploiting the production potential of aroids. This will also help in greater harvest per every drop of irrigation water resulting in higher water use efficiency.

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