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"JÚLIO DE MESQUITA FILHO"
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MEILING LI

**RESPONSE OF TARO [*Colocasia esculenta* (L.) Schott] GROWTH, YIELD, AND
CORM QUALITY TO VARYING WATER REGIMES AND SOIL TEXTURES**

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CORM QUALITY TO VARYING WATER REGIMES AND SOIL TEXTURES**

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Advisor: Prof. Dr. Lin Chau Ming

Coorientator: Prof. Dr. Angélica Cristina

Fernandes Deus

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AUTORA: MEILING LI

ORIENTADOR: LIN CHAU MING

COORDINADORA: ANGÉLICA CRISTINA FERNANDES DEUS

Aprovada como parte das exigências para obtenção do Título de Doutora em AGRONOMIA (HORTICULTURA), pela Comissão Examinadora:



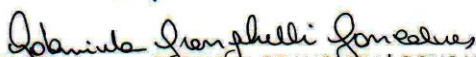
Prof. Dr. LIN CHAU MING
Horticultura / Faculdade de Ciências Agronômicas de Botucatu



Prof. Dr. DIRCEU MAXIMINO FERNANDES
Solos e Recursos Ambientais / Faculdade de Ciências Agronômicas de Botucatu



Prof. Dr. JOÃO CARLOS CURY SAAD
Engenharia Rural / UNESP - Faculdade de Ciências Agronômicas de Botucatu



Pós-Doutoranda GABRIELA GRANGHELLI GONÇALVES
Horticultura / Faculdade de Ciências Agronômicas



Prof.ª Dr.ª LAÍS LORENA QUEIROZ MOREIRA
Fertilidade do Solo / Instituto Federal do Norte de Minas Gerais

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**To my beloved grandmother,
Li Fan Shi,
I dedicate.**

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ABSTRACT

Irrigation is an important agricultural practice for the cultivation of taro, however, there are few experimental results focus on this practice in Brazil, and there is no information on water requirement for this crop under different soil textures in São Paulo State. Therefore, the objective of this work was to evaluate the development, biomass and corm quality of taro under varying water regimes and soil textures. The experiment was conducted from 2016 to 2017 with two harvests, in a greenhouse of Agronomical Sciences College, São Paulo State University (UNESP), Botucatu, São Paulo, Brazil. The five irrigation levels were 20%, 60%, 100%, 140%, and 180% of crop water requirement (ET_c), with 100% ET_c as the control. And three soil textures: clay soil (CS), sandy clay loam soil (SCL) and sandy soil (SS) were used. Results showed that plant height, petiole diameter, leaf number and area, above-ground, root, and corm fresh/dry weight, corm number and diameter of taro were lower at 20% and 60% ET_c , and higher at 140% ET_c and 180% ET_c when compared with 100% ET_c . SS exhibited higher leaf number at all water regimes, whereas leaf area for SS was higher than SCL and CS at 20% ET_c . For the first harvest, SCL showed higher root fresh/dry weight, and SS exhibited higher corm dry weight than the other two soils. The highest water-use efficiency (WUE) and index (HI) were detected at 20% ET_c . For the second harvest, SS showed higher root and corm fresh weight, corm number and diameter. The 20% ET_c had the highest WUE, whereas the lowest HI was observed at the same water regime; The highest WUE and lowest HI were observed in SS. Generally, reducing sugars and starch content increased with the increase in water regime, while a different trend was observed in total soluble solids, total total titratable acidity, and protein content in taro corm. SS was had higher total sugars, reducing sugars, and starch content than the other two soils. Briefly, irrigation management plays an important role in improving the growth of taro. The application of sandy soil should be one good way for taro to adapt limited water availability conditions.

Keywords: Irrigation. Soil type. Water-use Efficiency. Canopy Size. Chemical Composition. Water-stress.

RESUMO

A irrigação é uma prática agrícola importante para o cultivo do inhame, entretanto, há poucos resultados experimentais focados no Brasil, e não há informações sobre a necessidade de água para essa cultura sob diferentes texturas de solo no estado de São Paulo. Objetivou-se com o presente trabalho avaliar o desenvolvimento, biomassa e qualidade dos tubérculos do inhame sob diferentes lâminas de irrigação e texturas de solo. O experimento foi conduzido de 2016 a 2017 com duas colheitas em casa de vegetação na Universidade Estadual Paulista (FCA/UNESP), Botucatu. Estudou-se cinco lâminas de irrigação: 20%, 60%, 100% (controle), 140% e 180% da necessidade de água da cultura (ET_c), e três texturas de solo: solo de textura argilosa (CS), solo de textura média (SCL) e solo de textura arenosa (SS). Os resultados mostraram que a altura da planta, diâmetro do pecíolo, número de folhas, área foliar, peso fresco/seco da parte aérea, da raiz e do tubérculo, número e diâmetro de tubérculo do inhame foram menores em 20% e 60% ET_c e maiores em 140% and 180% ET_c quando comparado com 100% ET_c . SS apresentou maior número de folhas em todas as lâminas de irrigação, enquanto a área foliar para SS foi maior que SCL e CS em 20% ET_c . Para a primeira colheita, SCL apresentou maior peso fresco/seco da raiz, e SS apresentou maior peso seco do tubérculo do que os outros dois solos. A maior eficiência no uso da água (WUE) e índice de colheita (HI) foram detectados em 20% ET_c . Para a segunda safra, SS apresentou maior peso fresco e de tubérculo, número e diâmetro de tubérculo, comparados com os outros dois solos. A 20% ET_c apresentou a maior WUE, enquanto a HI menor foi observado nessa mesma lâmina; A maior WUE e a menor HI foram observadas no SS. Geralmente, açúcares redutores e teor de amido aumentaram com o aumento na lâmina de irrigação, enquanto uma tendência diferente foi observada em sólidos solúveis totais, acidez total titulável e teor de proteína no tubérculo de inhame. O SS apresentou maiores açúcares totais, açúcares redutores e teor de amido do que os outros dois solos. A irrigação desempenha um papel importante na melhoria do crescimento do

inhame. O solo arenoso pode ser uma boa maneira para cultivar o inhame nas condições limitadas de disponibilidade de água.

Palavras-chave: Irrigação. Tipo de Solo. Eficiência no Uso da Água. Tamanho da Copa. Composição Química. Estresse Hídrico.

SUMMARY

GENERAL INTRODUCTION.....	15
CHAPTER 1 DEVELOPMENT AND FRESH BIOMASS OF TARO (<i>Colocasia esculenta</i> (L.) Schott) RESPONSE TO VARIOUS WATER REGIMES AND SOIL TEXTURES.....	22
ABSTRACT.....	22
1.1 INTRODUCTION.....	23
1.2 MATERIALS AND METHODS.....	24
1.3 RESULTS.....	29
1.4 DISCUSSION.....	34
1.5 CONCLUSION.....	36
ACKNOWLEDGEMENTS.....	37
REFERENCES.....	37
CHAPTER 2 RESPONSE OF TARO TO VARYING WATER REGIMES AND SOIL TEXTURES.....	42
ABSTRACT.....	42
2.1 INTRODUCTION.....	43
2.2 MATERIALS AND METHODS.....	44
2.3 RESULTS.....	50
2.4 DISCUSSION.....	53
2.5 CONCLUSION.....	55
ACKNOWLEDGEMENTS.....	56
REFERENCES.....	56
CHAPTER 3 CHEMICAL COMPOSITION AND DRY BIOMASS OF TARO RESPONSE TO VARYING WATER REGIMES AND SOIL TEXTURES.....	61
ABSTRACT.....	61
3.1 INTRODUCTION.....	62
3.2 MATERIALS AND METHODS.....	63
3.3 RESULTS.....	68

3.4 DISCUSSION.....73

3.5 CONCLUSION.....75

ACKNOWLEDGEMENTS.....75

REFERENCES.....75

FINAL CONSIDERATIONS.....81

REFERENCES.....83

GENERAL INTRODUCTION

Taro (*Colocasia esculenta* L. Schott) is known by various names, including dasheen, eddoe, cocoyam, or tania (ONWUEME, 1999; PRAGATI; KAUSHAL, 2015; CABI, 2017). It is a tuber crop from the family of Araceae monocot, was spreaded from Asia to eastern of Southeast Asia and then to China, Japan, and Pacific Islands (SINGH et al., 2007; MODI, 2007; MARE, 2009). Belonging to the subfamily of Aroideae (LEBOT, 2009), which includes about 100 genera and 1500 widely distributed species (MERLIN, 1982).

The above-ground (Figure 1) of taro is composed with large leaves and long petioles (ONWUEME, 1978; PURSEGLOVE, 1972). The leaf blade ranges from 25 to 85 cm in length and 20 to 60 cm in width (PURSEGLOVE, 1972), the petioles measured between 1 and 2 m in length (ONWUEME, 1978; PURSEGLOVE, 1972). Taro has starchy underground stems, widely dilated, which are designated as corms (BROUK, 1975; COURSEY, 1968; PLUCKNETT, 1970).

Figure 1 Taro leaves, petioles, roots, and corms.



Source: SCIENCE PICS, 2017

Taro corm is composed, externally, of concentric rings of scars and leaf scales (WINTON; WINTON, 1935). It has one or more minor secondary corms that arise from

lateral sprouts present under each scale or leaf base (ONWUEME, 1978; WINTON; WINTON, 1935). There are highly variable to humidity, size, color and chemical composition for taro corm (PLUCKNETT, 1970; STRAUSS et al., 1980). The shape of corm varies from elongated to spherical with an average diameter of 15 to 18 cm (BROUK, 1975; ONWUEME, 1978; WINTON; WINTON, 1935). Generally, the taro root system is adventitious and fibrous (ONWUEME, 1978; PURSEGLOVE, 1972).

Taro flowers are not common in all cultivars. One author recorded that "The taros have been cultivated for so long while many of them never flowered and it is likely that no civilized man has seen a viable seed of taro" (BARRETT, 1928). This led to the supposition that taro seeds were indeed quite rare (KIKUTA, WHITNEY; PARRIS, 1938; MACCAUGHEY; EMERSON, 1913; WHITNEY, 1937; WILIMOT, 1936).

Taro growth, maturity, and harvest period depend on the cultivar. In the initial of planting the growth rate is slow but will increase rapidly after one to two months (ONWUEME, 1999). Taro has four physiological stages: dormancy, vegetative stage, reproductive stage, and maturity (MARE, 2009). The dormancy and vegetative stage is the period of root and leaf establishment (SIVAN, 1982). This stage is characterized by sprouting and root growth. The vegetative growth is marked by an increase in plant height, number of leaves and leaf area, and slow corm growth (TUMUHIMBISE et al., 2009), at this stage, the leaf and petioles are the dominant collectors for photo-assimilates (SINGH et al., 1998). The reproductive stage is the period of rapid corm development after five months planting age (SIVAN, 1982).

At the maturity stage, the growth of corm is at the peak, with a rapid increase in the formation of corms. This stage is a period of senescence of canopy size, associated with decreased plant height, leaf area, and leaf number, whereas with the continuous increase of corm size (SIVAN, 1982). At this stage there is a rapid decline in sprout growth, and reduction in the number of active leaves, decrease in average petiole length, total leaf area per plant, and decrease in plant height (ONWUEME, 1999; SILVA et al., 2008). According to Goenega (1995), a increase in biomass

occurred after obtaining maximum leaf area, and dry matter partition for the corms remained constant from 150 days after planting. Tumuhimbise et al. (2009) also reported that the maturity stage is a growth period in which the diameter and length of the corm increased rapidly over the 150 days.

Taro is produced and consumed mainly in subsistence, and the surpluses are sold as production crops, which plays an important role in Fighting against hunger (ONWUEME, 1999). The production characteristics include total weight of corms, number of corms, and individual weight per corm and so on (MARE, 2009). In 2017, the world production of taro reached 10.222 million tonnes in 1.724 million hectares (ha) of land, with Nigeria accounting for about 3.901 million tonnes, followed by China with 1.656 million tonnes, and Ghana with 1.512 million tonnes (FAO, 2019). In addition, taro corm has a broader complement of nutrients than other tuber crops (KAUSHAL et al., 2015; FILHO et al., 1997), it is superior to potatoes (*Solanum tuberosum*), sweet potatoes (*Ipomoea batatas*), cassava (*Manihot esculenta*) and yam (*Dioscorea* L.).

In Brazil, its importance is mainly linked to the center-south region of the country, specifically in the states of Minas Gerais, Rio de Janeiro and Espírito Santo, where most of the national taro production concentrated. Taro is associated with family farming in producing regions, since its technological input needing is low (GONDIM et al., 2007). For example, in the state of Rio de Janeiro, such as Cachoeiras de Macacu and Magé, they produce more than 8,000 t/year in total, which represents approximately 40% of the crop's production of the state (CIDE, 2007).

Compare with taro leaf and petiole, taro corms are the primary use of its consumption, since they are sources of carotene, potassium, calcium, phosphorus and iron (DEO et al., 2012). As good resources for infant feeding because its starch is easily digestive, which is helpful for people with problems digestive (JOUBERT and ALLEMANN, 1998; ONWUEME, 1999; SHANGE, 2004). They also contain higher starch content than potatoes and sweet potatoes (TUMUHIMBISE et al., 2009), which is suitable for gastric patients.

In addition, taro has a number of medicinal uses (PAUL; BARI, 2011). Taro corms can be used as an abortifacient, as for treating tuberculous ulcers, pulmonary congestion, fungal abscesses in animals, and as anthelmintic. Foliage is used as a hemostasis and poultice, and the petiole is used as a treatment for wasp stings (WILBERT, 1986) which is also a good source of dietary fiber. Additionally, high levels of dietary fiber in foods are also advantageous for their active role in regulating intestinal transit (WILBERT, 1986).

As an important tuber crop taro can grow in many tropical and subtropical countries (SLOAN et al., 2016). The optimum temperature for taro growth ranges from 21°C to 27°C, and well distributed summer rains of 1000mm or more additional irrigation is preferred (WILSON et al., 2013). However, under tropical conditions, the crop is often subjected to unfavorable growth conditions, due to stress of water deficit, low humidity and high temperature which may limit productivity due to their harmful effects on taro growth (PARDALES, 1985).

Taro yield and quality fluctuate due to the differences in cultivar, irrigation management, soil textures, planting density, levels of fertilizer application, among other environmental factors (MANNER; TAYLOR, 2010; CHUN-FENG; KUN, 2004). Compared to other tuber crops, the plant is characterized by the ability to grow under adverse conditions, such as excess water, high temperature, shaded habitat, and tropical forests (SMITH, 2006). This plasticity in adaptation has made it possible to use taro in agroforestry systems, including intercropping, between shrub, and tree species (ANUEBUNWA, 1992; OLIVEIRA et al., 2006), or in lines (OLIVEIRA et al., 2007). In addition, chemical composition of tuber crops differs with different cultivars (MARE, 2009), it is also influenced by climatic conditions, which are dependent upon the site and planting date. Another important factor for the success of irrigated agriculture is irrigation water management, since it is one of the major concerns related to the agricultural system (BRITO, 2015).

The amount of water available with its distribution pattern results in increased production and longer growing period. According to Daff (2011), it is important to ensure a constant availability of water during the growing season of taro, since water scarcity can cause water stress, which results in reduced yield, malformed and poor-quality corms. In order to provide such water supply, irrigation should be used, especially where there is irregular precipitation (JOUBERT; ALLEMANN, 1998). The main methods of irrigation are by flood, furrows, sprinkler, pivots and localized (micro sprinkler and drip irrigation). The choice of the appropriate irrigation method depends on several factors, such as topography, soil physical properties, culture, available water quality, among others. As one of the most efficient method used in irrigated agriculture, drip irrigation system is able to promote higher yields with greater efficiency in water use.

On the other hand, taro can grow in a wide variety of soil textures, from clay soils to sandy soils (ONWUEME, 1999). However, the taro produce better when planted in fertile soil, rich in organic matter with high capacity water retention. A slightly acid soil with pH of 5,5 to 6,5 with moderate clay content is considered ideal (ONWUEME, 1999; SAFO-KANTAKA, 2004). Soil texture refers to the proportion of the sand, silt and clay particles of soil, which varies according to the type and mineral composition of the source material and the chemical weathering processes involved in soil formation. It is an very important physical property of soil, as it influences the soil physical and chemical behavior (BOWMAN; HUTKA, 2002), with influence on water retention capacity and its availability, nutrient leaching and aeration (HUNT and GILKES, 1992), thus, soil texture is also used to estimate the other soil properties, particularly water properties related with soil. Soil texture also influences root growth indirectly, whereas root response directly to soil textures in water, oxygen and nutrient availability in soil, soil aeration and nutrient content (GLINSKI; LIPIEC, 1990). In addition, the physical and chemical properties of the soil affect the quantity and the movement of these substances essential for the growth of the plants. The first concern in the relationship between soil texture and plant growth will be the behavior

of root in different soil textures (GLINSKI; LIPIEC, 1990; HILLEL, 1982).

Furthermore, as one of the most limited factor for plant growth (FISCHER; TURNER, 1978), water availability for plants depends heavily on soil texture, which controls hydraulic conductivity and field capacity (WALTER; STADELMAN, 1974). As the infiltration of rainwater into coarse-textured soils is much deeper than in fine textured soils, the evaporation of coarse-textured soils is much smaller than that of fine-textured soils after precipitation (WALTER; STADELMAN, 1974). Thus, knowing the textural classes of soils is an important step in using management practices that maximize productivity and minimize environmental damage (HILLIARD; REEDYK, 2014).

However, little information is found on the water stress tolerance of taro under different soil textures. Sivan (1995) and Sahoo et al. (2006) observed that canopy size of taro decreased in response to water stress. Uyeda et al. (2011) evaluated the response of taro to five irrigation levels (50%, 100%, 150%, 200%, and 250% ET_0 - reference evapotranspiration) and found maximum taro yield at 150% ET_0 . A study by Buragohain et al. (2013) focus on taro quality response to 20 cultivars in Nagaland reported that the corm length and diameter reflected wide variation among the cultivars, as well as the starch content, corm humidity, and corm number. Kaensombath et al. (2012) reported that the yield of taro leaves and petioles were larger with more frequent harvesting, while corm yield was not affected by harvest interval. Also, based on crop water requirement (ET_c), Mabhaudhi et al. (2013) investigated the effect of three water regimes on growth of taro. They found that leaf number and leaf area decreased at 60% and 30% ET_c . In addition, taro yield was higher at optimum irrigation (100% ET_c) when compared with 60% and 30% ET_c , whereas water-use efficiency (WUE) was relatively stable among water regimes.

Research on taro is still suffering from the lack of scientific information in relation with soil texture. Filipović et al. (2016) reported that the soil with a high content of clay significantly improved the corm number per plant of Jerusalem artichoke (*Helianthus Tuberosus* L.). Martin and Miller (1983) studied the response of potato to deficit

irrigation under different soil textures (sandy and loam soil), they found that in sandy soil its yield greatly increased with increase in irrigation level. Furthermore, Katerji and Mastrorilli (2009) observed a significant reduction (22%-25%) in WUE in clay soil for potatoes, corn (*Zea mays* L.), sunflowers (*Helianthus annuus*), and sugar beets (*Beta vulgaris*), comparing with that detected in loam soil.

Chemical composition of taro corm has been well documented by previous researches (ONWUEME, 1978; KAUSHAL et al., 2015). The proximal composition of taro corm varies depending on variety, growing condition, soil type, moisture and fertilizer application, maturity at harvest, post-harvest management, and storage (ONWUEME, 1978; BRADBURY et al., 1985; BRADBURY; HOLLOWAY, 1988). Its nutritional composition is low in protein and fat like other root crops, but high in carbohydrate. The moisture content of taro is also very high, which generally ranges from 60-83% (HUANG, et al., 2007). Taro starch is the most important component (JANE, et al., 1992) of taro corm (70-80% dry weight basis). It contains about 11% crude protein on a dry weight basis. However, the chemical composition research of taro is still suffering from the lack of scientific information in relation with water regime and soil texture.

It is evident from the literatures reported above that the majority of agronomical knowledge about the crop was derived from environments outside Brazil, basic agronomic studies on taro occurring in Brazil are still lacking. Thus, the focus of the current study was to study the response of taro development, biomass, and corm quality to varying water regimes and soil textures.

CHAPTER 1 DEVELOPMENT AND FRESH BIOMASS OF TARO (*Colocasia esculenta* L. Schott) RESPONSE TO VARYING WATER REGIMES AND SOIL TEXTURES

Meiling Li¹; Angélica Cristina Fernandes Deus²; and Lin Chau Ming³

¹ MS., Department of Horticulture, Agronomical Sciences College, São Paulo State University, José Barbosa of Barros Street, 1780. Zip-Code: 18.610-307 - Botucatu, SP, Brazil. Email: lilmeilinghappy@outlook.com. Corresponding author.

²Post Doc., Department of Soil and Environmental Resources, Agronomical Sciences College, São Paulo State University, José Barbosa of Barros Street, 1780. Zip-Code: 18.610-307 - Botucatu, SP, Brazil.

³ Prof., Department of Horticulture, Agronomical Sciences College, São Paulo State University, José Barbosa of Barros Street, 1780. Zip-Code: 18.610-307 - Botucatu, SP, Brazil.

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ABSTRACT

In the current study, the effects of water regime and soil texture on growth and development of taro were investigated. For this aim, the taro was grown at five water regimes (20%, 60%, 100%, 140%, and 180% ET_c - crop water requirement) in three soil textures (clay, sandy clay loam, and sandy soil). The experiment was conducted in a greenhouse, and two harvests of taro were analyzed. Plant height (PH), petiole diameter (PD), above-ground fresh weight (AFW), root fresh weight (RFW), corm number (CN), and corm diameter (CD) were lower at 60% and 20% ET_c relative to 100% ET_c, while 140% ET_c and 180% ET_c showed higher PH, PD, AFW, RFW, CN, and CD, compared with that of 100% ET_c. The 20% ET_c was observed to have the highest harvest index (HI) in the first harvest, whereas in the second harvest, 20% ET_c had the lowest HI. With respect to soil texture, a lower HI was observed in sandy soil in the second harvest, whereas SS showed significantly greater RFW, CN, and CD, suggesting that taro may have high potential to tolerant water stress in sandy soil.

Keywords: Irrigation, Soil type, Tuber crop, Corm number, Harvest index.

1.1 INTRODUCTION

Worldwide shortage of freshwater resources has focused attention on developing innovative water-saving irrigation strategies in order to reduce the pressure on freshwater resources (Ahmadi et al., 2011), and a rapid increase in global population growth demands an increase in production and diversification of crops. Root and tuber crops can play an important role in addressing this issue (Paul and Bari, 2011). As one tuber crop, taro (*Colocasia esculenta* L. Schott) can survive in conditions which considered to be adverse to the growth of other crops, due to the inherent characteristics of most Araceae, such as tolerance to water stress, climatic stress, and shade (Zárate et al., 2003). Taro is an important tuber crop to ensuring food security (Melese, 2017), which is also one of the least water-efficient crops (Uyeda et al., 2011, Daryanto et al., 2016). Both the amount of water available and its distribution have a significant effect on taro growth, which may interfere with its yield (Daryanto et al., 2016).

Researches on taro have been rather slow, as taro is less popular for the researchers compared with other tuber crops (Mabhaudhi et al., 2014). It is reported that limited water availability resulted in reduced plant growth (Hussain et al., 2008). Lower plant height of taro was reported under limited water availability by Sivan (1995) in taro varieties subjected to water stress. Sahoo et al. (2006) also observed significant reductions in plant height with an increase in water stress, conversely, the author reported a minimum reduction in yield. Mabhaudhi et al. (2013) tested taro response to three water regimes based on crop water requirement (ET_c), they found that corm number per plant was 13% and 11% higher at 60% ET_c , respectively, compared with 100% and 30% ET_c . In addition, as one trait have been extensively utilized for yield improvement in cereals and other crops (Sinclair, 1998; Roy Chowdhury, et al., 2012), the harvest index of taro response to irrigation treatment and soil texture was rarely reported. Bussell et al. (1998) reported that the harvest index of taro is generally higher in the high watering-level treatment (16 mm water/day) compared with the low watering-level treatment (5.8 mm water/day). However, in line

with the observations reported by Mabhaudhi et al. (2013), the harvest index was 14% and 7% lower at 100% ET_c relative to 60% and 30% ET_c , respectively.

When assessing the suitability for the cultivation of taro, soil texture is one of the most important characteristics to be taken into account (Filipović et al., 2016). Martin and Miller (1983) studied the response of potatoes to deficit irrigation as affected by soil texture (sandy and loam soil), and found that potato yield increased greatly with an increase in irrigation level (from 0% to 70% - 80% ET_0) in sandy soil. Irrigation levels above this had minimal effect, which is probably because sandy soil has a lower water-holding capacity than loam soil. Filipović et al. (2016) reported that the soil with a high content of clay significantly stimulated an increase in the corm number per plant of Jerusalem artichoke (*Helianthus Tuberosus* L.).

However, there is no comprehensive study investigated the response of taro to different irrigation levels under varying soil textures. As such, the aim of this study was to evaluate the growth and development of taro to five water regimes and three soil textures.

1.2 MATERIALS AND METHODS

Site description. The present investigation was carried out from May 31, 2016 to March 1, 2017, in a greenhouse of the Agronomical Sciences College, São Paulo State University (UNESP), Botucatu (22°51'S; 48°27'W), São Paulo, Brazil. The dimensions of the greenhouse are 7 meters in width and 30 meters in length, with 6 meters in height at the highest point. During the experimental period, the average temperature was 21.0 °C, the average ET_0 was 3.56 mm/day, and the average air humidity was 62.1%, as shown in Table 1.1.

Table 1.1 Average maximum and minimum of temperature, air humidity and ET_0 in the greenhouse during the experiment period, São Paulo, Brazil.

Month/Year	ET_0 (mm/day)	Tmax (°C) ^a	Tmin (°C) ^b	Hmax (%) ^c	Hmin (%) ^d
July 2016	2.11	27.53	10.54	85.27	36.55
August 2016	2.68	28.19	13.22	79.94	38.48
September 2016	2.70	29.22	13.73	76.43	37.43
October 2016	3.28	27.77	16.57	82.06	36.26
November 2016	3.67	28.79	17.16	86.39	35.86
December 2016	3.44	29.01	18.14	86.73	33.00
January 2017	5.30	28.80	19.70	98.40	47.20
February 2017	5.30	29.20	18.40	96.10	37.10

^a Temperature maximum; ^b Temperature minimum; ^c Air humidity maximum; ^d Air humidity minimum.

Plant material and experimental design. The taro cultivar selected for evaluation was ‘Chinese’. There are four physiological stages (Mare, 2009) for its growth cycle: dormancy, vegetative stage, reproductive stage, and maturity. The experimental design was a randomized complete block design with 15 treatments (Figure 1.1), resulting from the combination of five water regimes (20%, 60%, 100%, 140%, and 180% ET_c) and three soil textures (clay soil, sandy clay loam soil, and sandy soil), replicated four times, with two plants per replication, for a total of 120 plants. And the 100% ET_c was used as the control. Each pot (replication) had the capacity of 25 L with one plant in it, a plant spacing in the present study was 0.6 m × 0.5 m (Figure 1.2-A).

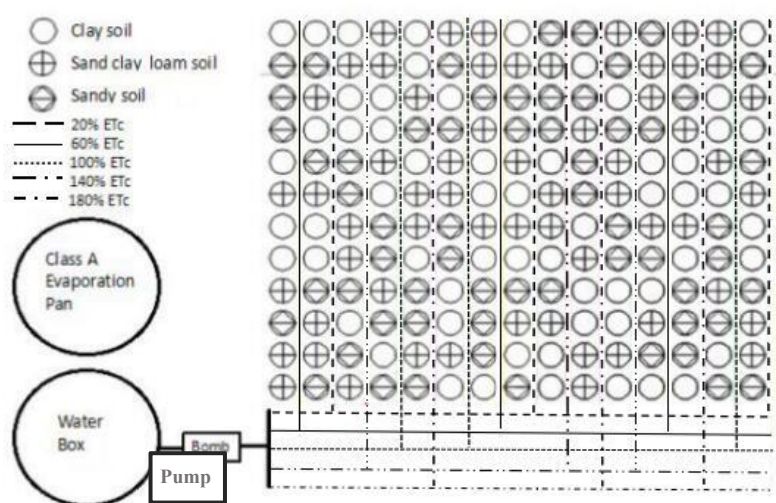


Figure 1.1 Experimental design.

Taro propagation. Taro propagation for corms commercial exploitation is performed exclusively by planting the corm, which is the major commercial product (Puiatti, 2001). The 400 corms weighing between 30g and 50g were selected for taro propagation. They were sown in 400 mL plastic cups (with three holes at the bottom of the cup), which were filled with soil and substrate. A soil to substrate ratio was 1:1 by volume. The soil used for propagation was sandy clay loam soil (SCL). And the substrate applied for propagation was suitable for tropical conditions and had the following characteristics: a moisture content of 60%, a water-holding capacity of 130% (both by weight), a bulk density of 200 kg m^{-3} , a pH of 5.8, and an electrical conductivity of 2.0 mS cm^{-1} . The 120 seedlings with similar sizes (approximately three leaves per seedling) were selected and transplanted into the pots at 48 days after sowing.

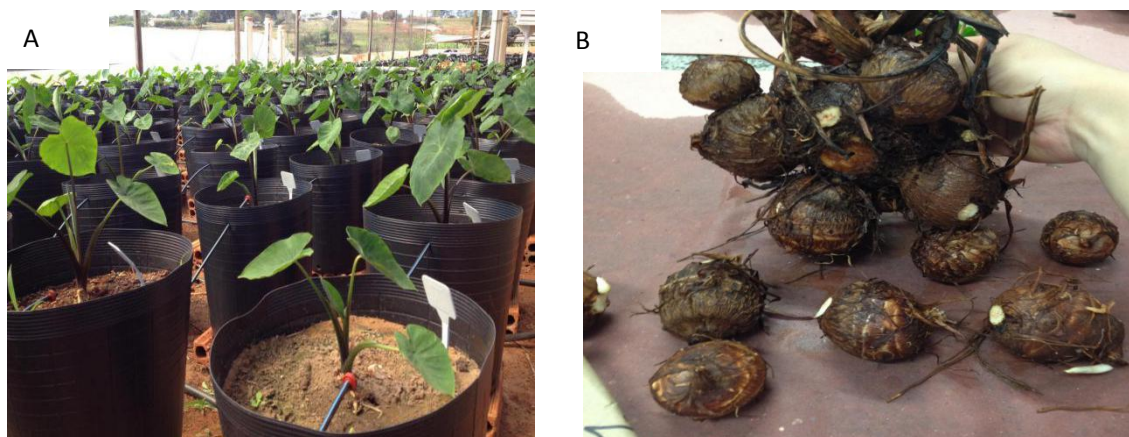


Figure 1.2 Taros in pots in greenhouse (A) and taro corms in harvest (B).

Soils, organic compost, and water. The soils applied in the current study were collected from the arable layer, at the 0-20 cm depth, from the farm of Agronomical Sciences College, São Paulo State University, Botucatu, São Paulo, Brazil. For soil fertility and texture analyses, each soil was air-dried and sieved through a 2 mm mesh. The pH (CaCl_2), organic matter (OM), P, H + Al, K, Ca, and Mg, SB (sum of bases), CEC (cation exchange capacity), and BS (base saturation, %) were determined according to the methodology reported by Raij et al. (2001). The particle size was determined using the pipette method (EMBRAPA, 2006). And the soil texture was classified according to FAO (2006). Soil analysis results are shown in Table 1.2.

Table 1.2 Textural and chemical characteristics of soils used in the experiment.

Textural class	Sandg/Kg	Clay	Silt	pH CaCl ₂	O.M g/dm ³	P _{resina} ^m mg/dm ³	H+Al	K	Ca	Mg	SB	CEC	BS%
CS	436	456	108	3.9	14	5	87	0.5	3	1	5	92	5
SCL	652	291	57	4.1	16	4	77	0.7	3	1	4	81	5
SS	957	34	9	4.7	9	4	17	1.1	7	3	10	28	38

CS = clay soil; SCL = sandy clay loam; and SS = sandy soil. ^m P_{resin} is a method used for the analysis of phosphorus in soil.

The soils were corrected using limestone before transplanting. According to the recommendation of Bulletin 200 (Aguiar et al., 2014), the acidity correction was calculated based on the need for liming to raise the base saturation of each soil to 60%. Based on soil fertility results and the recommendation of the Bulletin 200 (Aguiar et al., 2014), 200 mg L⁻¹ of P, 30 mg L⁻¹ of N, and 40 mg L⁻¹ of K (using triple superphosphate, urea, and potassium chloride, respectively) were applied to each pot before transplanting (soils were kept wet for fertilization). The amounts of corrective and fertilizer applied per pot, in grams, were calculated considering the pot capacity (25 L).

The compost heap was done twice (in September and December of 2016, respectively) during the experiment with 1.5 L of organic compost (Table 1.3) applied above the soil per pot. The irrigation water used was from Sabesp, which is responsible for planning, executing and operating basic sanitation services throughout the State of São Paulo of Brazil. According to the chemical characteristics of the irrigation water, it was classified as C1S1 (Richards, 1954), and does not show restriction for irrigation. Water analysis results are shown in Table 1.4.

Table 1.3 Chemical characteristics of organic compost used in the experiment.

		O.M	N	P ₂ O ₅	K ₂ O	Ca	Mg	S	U-65°C	C	Na	Cu	Fe	Mn	Zn
pH	C/N	 %								 mg/Kg					
7.7	11/1	34	1.8	1.4	0.6	1.8	0.4	0.3	13	19	609	63	10005	348	120

Table 1.4 Chemical characteristics of water used in the experiment.

	N	P	K	Ca	Mg	S	Na	B	Cu	Fe	Mn	Zn	C.E
pH	 mg/L												 μS/cm
7.3	4	1	22	18	10	5	3.80	0	0	0.16	0	0	73

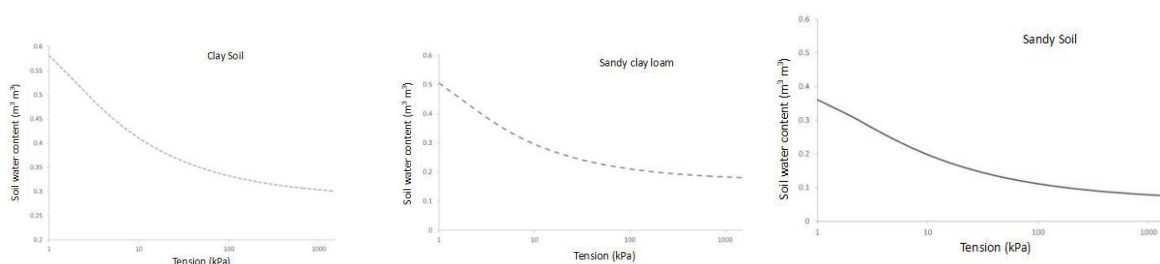


Figure 1.3 Tension of the three soils

Irrigation system. The irrigation system used in the experiment was drip irrigation. Irrigation was delivered using in-line pressure-compensating emitters, with a flow rate of 2.0 L h^{-1} , which were positioned on each pot using a micro-tube with a connector. The time of irrigation and the volume of water to be applied were determined by a simplified water balance, using the Class A Evaporation Pan method (CAEP; Peixoto et al., 2010), which is a standard used to measure the water evaporation.

In the present investigation, the irrigation management was based on the evaporation value of the CAEP, pan coefficient (K_p), and crop factor (K_c) associated with phenological stages of taro (Allen et al., 1998). The evaporation value of the CAEP was measured according to Allen et al. (1998). The evaporation value and K_p were used to calculate the ET_0 (Equation 2), which differs with the change of local climatic conditions. The value of K_p applied in the current study was 1, as recommended by Prados (1986). The growth cycle of taro is of approximately seven months (Lebot, 2009). K_c values of taro were as described by Fares (2008), where $K_{c \text{ initial}} = 1.05$ (two months), $K_{c \text{ med}} = 1.15$ (four months), and $K_{c \text{ late}} = 1.1$ (one month). According to the values of K_c and ET_0 , ET_c (Equation 1) was calculated using the single crop coefficient approach, as described by Allen et al. (1998):

$$ET_c = ET_0 \times K_c \dots\dots\dots [1]$$

where: ET_c = crop water requirement, ET_0 = reference evapotranspiration, and K_c = crop factor; and

$$ET_0 = CAEP \times K_p \dots\dots\dots [2]$$

where: CAEP = Evaporation value of Class A Evaporation Pan, and K_p = Pan coefficient.

All treatments were irrigated with 100% ET_0 since July 18, 2016. Irrigation treatments began after one month of transplanting. Irrigation was performed every morning to ensure water availability during the peak periods of plant demand during the day. The last irrigation occurred on February 28, 2017. The total irrigation water applied (WU_t), taking the initial watering into account, ranging from 1580 mm (180% ET_c) to 1244 mm, 908 mm, 572 mm, and 236 mm for 140%, 100%, 60%, and 20% ET_c , respectively. During the experiment, two harvests were carried out, one on December 1, 2016 (at 135 days after transplanting), and another on March 1, 2017 (at 225 days after transplanting).

Data collection. Fifteen days after transplanting, Plant height (PH) and petiole diameter (PD) were performed once a month until the last harvest. PH was measured as the distance from the ground to the attachment point between the leaf petiole and the lamina of the tallest leaf. The PD was measured in centimeters, at the base of petioles (top of the soil) with a vernier caliper.

In the harvests, above-ground fresh weight (AFW) per plant (was measured only in the first harvest), root fresh weight (RFW) per plant, corm number (CN) per plant, corm diameter (CD, was measured only in the second harvest), and HI were measured. HI was calculated by the given formula (Thokchom et al. 2018),

$$\text{Harvest index} = (\text{Economic yield} / \text{Biological yield}) \times 100\% \dots \dots \dots [3]$$

where Economic yield - corm fresh weight per plant (Li et al. 2018), and Biological yield - was measured by summing AFW, RFW, and corm fresh weight per plant .

Statistical analysis. Analysis of variance (ANOVA) was used to statistically analyze data (plant height, petiole diameter, above-ground fresh weight, root fresh weight, corm number per plant, corm diameter and harvest index) using Sigmaplot® version 11.0 (ISI, San Jose, California, USA). The Tukey's Honest Significant Difference test (HSD) was used for multiple comparison tests, with a significance level of $\alpha = 0.05$.

1.3 RESULTS

Effects of water regime and soil texture on plant height (PH) and petiole diameter (PD) of taro. There was a significant difference ($p < 0.001$) in PH between

water regimes (Figure 1.4 a, c, and e), whereas there was no significant difference ($p = 0.440$) between soil textures (Figure 1.5 a, c, e, g, and i). Generally, taller plants were acquired at higher irrigation levels, 180% ET_c had the tallest taro (39cm, on average), followed by 140% ET_c . The PH decreased by 25% and 36% at 60% ET_c and 20% ET_c (Figure 1.4 a, c, and e), respectively, compared with the control treatment (100% ET_c). With respect to soil texture, the average PH was 32cm for the three soil types (Figure 1.5 a, c, e, g, and i). The PH increased with an increase in planting time until they reached a maximum plant height (which we call “PH peak”) and then declined. In the current study, “PH peak” was reached at a different time for different irrigation treatments. For 100%, 140%, and 180% ET_c , “PH peak” was reached at 26 weeks after planting, whereas for 20% ET_c and 60% ET_c the peak was reached at 18 and 22 weeks after planting (Figure 1.3), respectively.

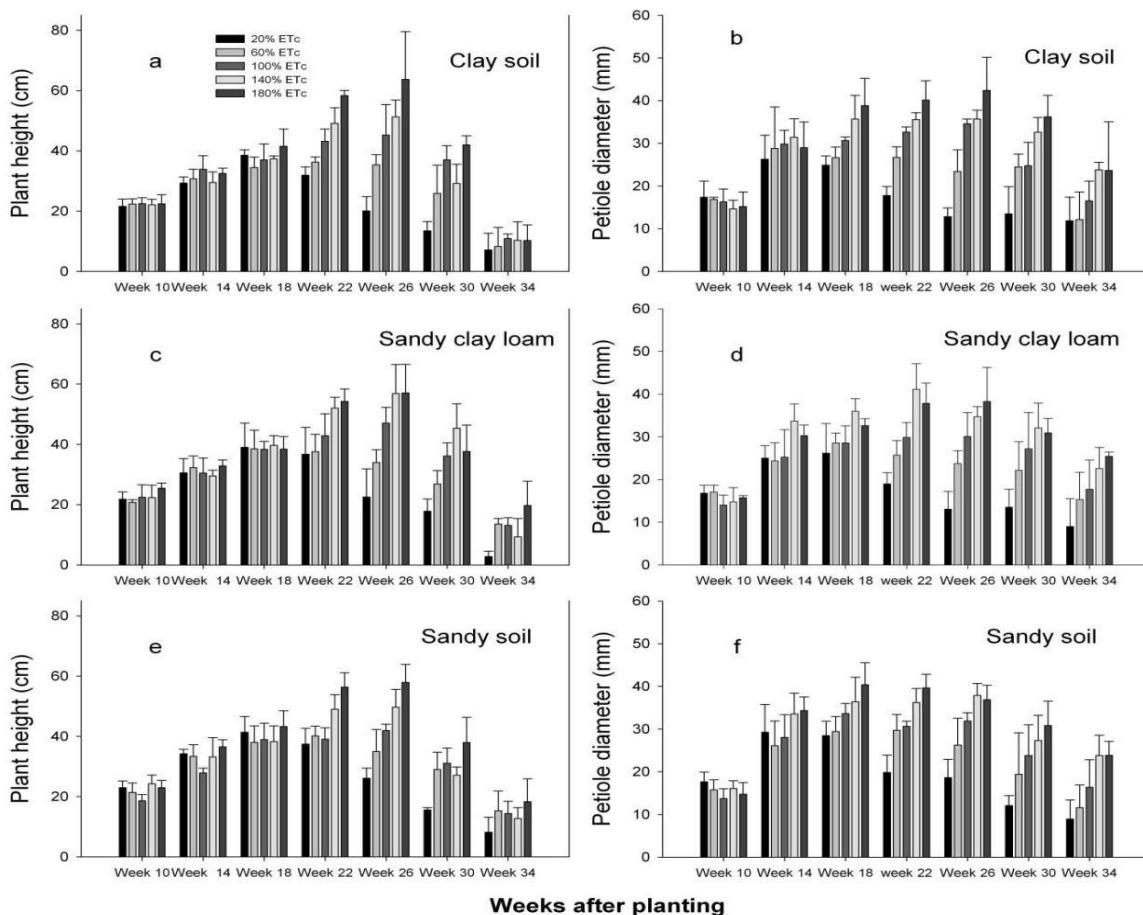


Figure 1.4 Effects of water regime on plant height and petiole diameter of taro.

Petiole diameter (PD) followed the similar trend as PH. There was a significant

difference in PD between water regimes ($p < 0.001$), no significant difference was observed between soil textures ($p = 0.603$). The PD increased by 23% and 19% (on average) at 180% and 140% ET_c , respectively, and decreased by 11% and 29% at 60% and 20% ET_c , respectively, compared with 100% ET_c (Figure 1.4 b, d, and f). Whereas PD for 140% ET_c was not significantly different from that for 180% ET_c ($p = 0.335$). The average PD kept relatively constant (26 mm) with respect to different soil textures (Figure 1.5 b, d, f, h, and j).

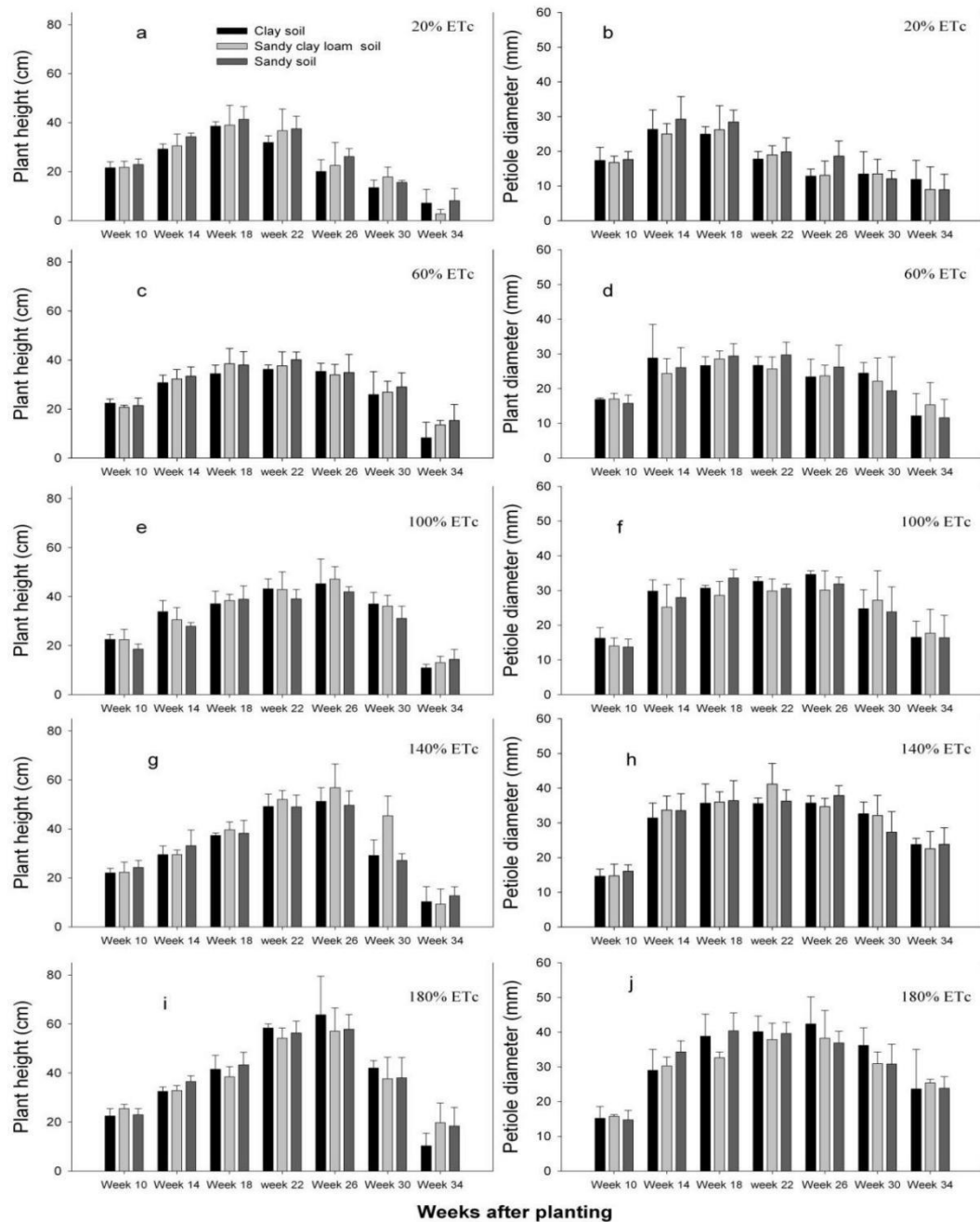


Figure 1.5 Effects of soil texture on plant height and petiole diameter of taro.

Effects of water regime and soil texture on the above-ground fresh weight (AFW), root fresh weight (RFW), corm number (CN), corm diameter (CD), and harvest index (HI). Above-ground fresh weight (AFW) showed highly significant differences between water regimes ($p < 0.001$). With respect to the differences observed between water regimes, the trend was $180\% ET_c > 140\% ET_c > 100\% ET_c > 60\% ET_c > 20\% ET_c$ (Table 1.5). No significant difference ($p = 0.062$) was observed for AFW between soil textures. There were significant differences between water regimes ($p < 0.001$), as well as between soil textures ($p = 0.017$) for RFW in the first harvest (Table 1.5). The interaction between irrigation treatment and soil type was also significant ($p = 0.040$). Water regime of $180\% ET_c$ had the highest RFW in all soil textures compared with the other irrigation treatments. Whereas there were no significant differences between soil textures at 20% , 60% , 100% , and $180\% ET_c$ (Table 1.5). The SCL soil showed higher RFW at $140\% ET_c$ in comparison with CS and SS. In the second harvest, significant differences were observed between water regimes ($p < 0.001$) as well as between soil textures ($p < 0.001$) for RFW (Table 1.6). The interaction between irrigation treatment and soil type was also significant ($p < 0.001$). In CS, $140\% ET_c$ showed the highest value of RFW among the irrigation treatments; In SCL, 20% and $180\% ET_c$ showed slight lower RFW compared with the other water regimes; whereas no significant difference was observed between 100% , 140% , and $180\% ET_c$ in SS. Interestingly, in this harvest, SS showed higher RFW, compared with CS and SCL, which is clearer at $20\% ET_c$ and $180\% ET_c$. This is indicating that SS may be more beneficial to the formation of taro root with long-term water stress.

Table 1.5 Response of Above-ground fresh weight, root fresh weight, corm number , and harvest index of taro to varying water regimes and soil textures in the first harvest.

Values in table are means (n=4).

Water regime	AFW (g plant ⁻¹)			RFW (g plant ⁻¹)			Corm number plant ⁻¹			Harvest index (%)		
	Soil texture			Soil texture			Soil texture			Soil texture		
	CS	SCL	SS	CS	SCL	SS	CS	SCL	SS	CS	SCL	SS
20% ET _c	29Da ^a	29Da	37Da	20Da	35Ba	33Ba	4Ca	5Da	5Ba	68Aa	66Aa	63Aa
60% ET _c	133Ca	102Ca	121Ca	70Ca	75Ba	72Ba	8BCa	8CDa	7Ba	46BCa	53ABa	56ABa
100% ET _c	179BCa	175Ba	220Ba	84Ca	104Ba	126Aa	11Ba	10BCa	14Aa	55Ba	52ABa	52ABa
140% ET _c	247Ba	248Aa	266ABa	137Bb	200Aa	144Ab	16Aa	13Ba	15Aa	55Ba	48Ba	53ABa
180% ET _c	343Aa	261Aa	300Aa	201Aa	253Aa	146Aa	16Aa	20Aa	20Aa	43Ca	46Ba	46Ba

AFW = above -ground fresh weight; RFW = root fresh weight; CN = corm number; and HI = Harvest index. CS = clay soil; SCL = sandy clay loam; SS = sandy soil. ^a Mean separation between water regimes within soil texture (capital letters) and between soil textures within water regime (lower case letters) by t-test at $\alpha = 0.05$.

Regarding the corm number (CN), there were significant differences between water regimes ($p < 0.001$) in both harvests, while a significant difference between soil textures ($p = 0.018$) was observed only in the second harvest (Table 1.6). It is evident from the results of Table 1.5 and Table 1.6 that CN increased significantly with increase in irrigation level. In line with the differences observed between soil textures in the second harvest, SS showed 6% and 32% higher CN, respectively, compared with CS and SCL (Table 1.6). As one key yield component, the variation in the number of corms observed in the current study may offer some meaningful information for choosing of irrigation level and soil type to cultivate taro. There were significant differences between water regimes ($p < 0.001$) and soil textures ($p = 0.026$) for corm diameter (Table 1.6). Corm diameter (CD) showed a similar trend with AFW, RFW, and CN. On average, 180% ET_c had 43% and 13% higher CD, respectively, compared with 20% and 60% ET_c (Table 1.6). In line with the differences observed between soil textures, CD for SCL (33.8 mm) and SS (34.4 mm) were similar while compared of the CS was 7% lower than the two soils (Table 1.6).

Regarding the harvest index (HI), there were significant differences between water regimes ($p < 0.001$) in the two harvests, whereas there was a significant

difference between soil textures ($p < 0.001$) in the second harvest. In the first harvest (135 days after planting), HI ranged from 43% to 68%; And in the second harvest (225 days after planting), it ranged between 92% and 98% (Table 1.5 and Table 1.6). In addition, in the first harvest, 20% ET_c had the highest HI, while no significant differences were observed between the other water regimes; In the second harvest, 20% ET_c was observed to have the lowest HI. With respect to the differences observed between soil textures in the second harvest, SS showed 2% and 1% lower HI, respectively, compared with CS and SCL (Table 1.6).

Table 1.6 Response of RFW, CN, CD, and HI of taro to varying water regimes and soil textures in the second harvest. Values in table are means (n=4).

Water regime	RFW (g plant ⁻¹)			Corm number plant ⁻¹			Corm diameter (mm)			Harvest index (%)		
	Soil texture			Soil texture			Soil texture			Soil texture		
	CS	SCL	SS	CS	SCL	SS	CS	SCL	SS	CS	SCL	SS
20% ET _c	9Bb ^a	9Bb	11Ba	6Da	4Ca	7Ca	23Ca	27Ba	28Ca	93Ca	93Ca	94Aa
60% ET _c	9Bb	14ABab	18Ba	9CDa	10BCa	11BCa	30Bb	35Aa	34Ba	96Ba	94BCa	95Aa
100% ET _c	9Bb	20Aab	29ABa	14BCa	12ABa	17ABa	34ABa	36Aa	34Ba	97Aa	95BCa	94Aa
140% ET _c	13Ab	14ABab	26ABa	18Bab	13ABb	20Aa	35Aa	35Aa	38Aa	97Aa	97ABab	95Ab
180% ET _c	9Bb	10Bb	37Aa	24Aa	18Aa	21Aa	37Aa	36Aa	39Aa	98Aa	98Aa	92Ab

RFW = root fresh weight; CD = corm diameter. ^a Mean separation between water regimes within soil texture (capital letters) and between soil textures within water regime (lower case letters) by t-test at $\alpha = 0.05$.

1.4 DISCUSSION

Results observed above showing reduced plant height (PH) under lower limited water availability (20% and 60% ET_c) were consistent with reports by Mabhaudhi et al. (2013) and Sahoo et al. (2006). In addition, kinds of literature suggested that PH of taro increased (until the “plant height peak”) during the early growth stages before gradually declining (six months after planting) as they approached maturity (Fa’amatuaunu, 2016; Noor et al., 2015; Tumuhimbise et al., 2009; Onwueme, 1999). In the current study, the time of “PH peak” was reached at different time with respect to water regime. The “PH peak” was reached at eight and four weeks earlier at 20% and 60% ET_c, respectively, compared with the other water regimes. PD was also affected negatively by water stress as reported above in the current study (Figure 1.4

b, d, and f). As a prevention strategy for drought (Levitt, 1979; Turner, 1986), plants tend to cope with limited water availability and escape from water shortage through reducing its size (plant height and petiole diameter). Results reported above proved that plants tend to complete their life cycle earlier than normal to avoid drought damage (Onwueme, 1999).

Results of above-ground fresh weight (AFW) was only for the first harvest as in the second harvest there was almost no more fresh leaf or petiole. In this period, water played an important role in biomass accumulation of the above-ground, while soil texture had no effect on biomass accumulation. Soil water content and soil physical properties affect root growth of taro (Parker et al., 1989; Bowen, 2003), yet there is little information focus on how irrigation level and soil texture influence on root fresh weight (RFW) in taro production. Generally, a well-developed root system was built to enhance the capture of soil water under water-limited conditions (Passioura, 2006; Vurayai et al., 2011). The RFW of taro decreased with the decrease in water availability in the first harvest, which was inconsistent with the reports by Sivan (1995), who observed that the root/shoot in taro increased subjected to water stress. We can only hypothesis that the daily drip irrigation may have kept the root zone reasonably moist enough to discourage root growth. In addition, soil texture has influenced root growth as SS showed the highest RFW in the second harvest. That may be because of that the sand content of SS is more than 90% (Table 1.2), which is much easier to handle and more suitable for root growth (Filipović et al., 2016).

The CN showed the similar trend with CD with respect to water regime (Table 1.6). In line with the observations of soil texture, SS showed more CN, compared with CS and SCL (a similar trend with corm weight, Li et al., 2019), while for CD, there was no significant difference between SS and SCL. We speculate that soil texture had affected corm shape of taro. In SCL we could get more rounded corms, compared with that of CS and SS, as with higher CD in SCL, the corm fresh weight (Li, et al., 2019) and CN did not increase significantly. However, further investigation (for example corm length) is needed. Results for CN were inconsistent with the

investigation of Jerusalem artichoke by Filipović et al. (2016), they reported that composition with high clay content stimulated an increase in CN, while in the current study, SS showed the higher CN in both harvests.

Harvest index (HI) has been extensively utilized in cereals and other crops for yield improvement (Hay, 1995; Sinclair, 1998), it can be used as a target trait in biomass improvement of taro. Results for HI in the current study were inconsistent with the reports by Thokchom et al. (2018) who observed that the HI of taro was ranged from 57% to 83% with 120 days after planting, while it ranged between 43% and 68% with 135 days after planting (Table 1.5). This is out of expecting, generally, the HI increased with increase in growth age, which was proved in the study of Mabhaudhi et al. (2013), they reported that the HI was 14% higher with 8 months of growth age than 6 months. In addition, the contrary behavior of HI shown at 20% ET_c for the two harvests (Table 1.5 and Table 1.6) indicates that HI was not only significantly influenced by water regime, growth age also affects greatly on HI, but it may also influence the effect of water stress on HI. Soil texture had influenced significantly on HI. The SS was observed to have lower HI, compared with CS and SCL, although SS were observed to have significantly higher corm weight (Li et al., 2019) and RFW in the second harvest. It is indicating that the difference for corm weight between soil textures was lower than for RFW, as SS showed significantly lower HI than the other soil textures. Which proved that in SS taro could create a strong root system to have high ability to use water under water stress conditions, and ultimately increase the yield.

1.5 CONCLUSION

The research conducted here show that limited water availability caused the reduced plant height, petiole diameter, as well as reduced above-ground, root fresh weight, corm number per plant, and corm diameter. A contrary trend was observed in the two harvests for harvest index, as the highest harvest index was observed at 20% ET_c in the first harvest, while the lowest harvest index for the second harvest was observed at the same irrigation level. Which indicating lower water availability could

improve harvest index, while there is a limit of duration of water stress, when the irrigation treatment last more than this limit could negatively affect on taro harvest index and ultimately on its growth and biomass accumulation. In the second harvest, sandy soil was shown to have significantly higher root fresh weight, corm number, and corm diameter, while a lower harvest index, compared with clay and sandy clay loam soil. It is suggesting that under limited available water conditions, taro may be better adapt in sandy soils, as in which it shown to have higher biomass accumulation, and stronger root system to avoid or reduce water stress damage.

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CHAPTER 2 RESPONSE OF TARO TO VARYING WATER REGIMES AND SOIL TEXTURES*

Meiling Li¹; Angélica Cristina Fernandes Deus²; and Lin Chau Ming³

¹ MS., Department of Horticulture, Agronomical Sciences College, São Paulo State University, José Barbosa of Barros Street, 1780. Zip-Code: 18.610-307 - Botucatu, SP, Brazil. Email: lilmeilinghappy@outlook.com. Corresponding author.

²Post Doc., Department of Soil and Environmental Resources, Agronomical Sciences College, São Paulo State University, José Barbosa of Barros Street, 1780. Zip-Code: 18.610-307 - Botucatu, SP, Brazil.

³ Prof., Department of Horticulture, Agronomical Sciences College, São Paulo State University, José Barbosa of Barros Street, 1780. Zip-Code: 18.610-307 - Botucatu, SP, Brazil.

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ABSTRACT

Taro [*Colocasia esculenta* (L.) Schott] is a major root crop widely distributed in the tropics and subtropics. However, little information is found on its water stress tolerance under different soil textures. Therefore, this study aimed to evaluate the effects of five water regimes (20%, 60%, 100%, 140%, and 180% ET_c - crop water requirement) and three soil textures (clay, sandy clay loam, and sandy soil) on growth, yield, and water-use efficiency of taro. The experiment was conducted in a greenhouse, and two harvests of taro were analyzed. In both harvests, leaf number (LN), leaf area (LA), and corm yield (Y_c) were lower at 20% and 60% ET_c when compared with 100% ET_c , and higher at 140% ET_c and 180% ET_c when compared with 100% ET_c . Sandy soil (SS) exhibited higher LN at all water regimes than clay (CS) and sandy clay loam (SCL) soils. For LA, the values found in SS were higher at lower water regimes (20% and 60% ET_c). In the three types of soil, water-use efficiency (WUE) was significantly higher at 20% ET_c , i.e., 1.00 kg m⁻³ and 0.51 kg m⁻³, respectively, in the first and second harvest when compared with the other water regimes. In the second harvest, WUE and Y_c were significantly higher in SS when compared with CS and SCL, indicating that SS has a higher potential to improve WUE

of taro under limited water availability conditions.

Keywords: Irrigation, Soil types, Corm yield, Canopy size, WUE.

2.1 INTRODUCTION

Despite being a renewable resource, water availability varies. Nearly every country in the world experiences water shortages during certain periods of the year (Gleick, 1993), and more than 80 countries currently suffer from severe water shortage (Jin et al., 2007; Long et al., 2009). Owing to the competing demands for fresh water from various sectors of human enterprises, the increase in irrigation water-use efficiency is required for the sustained global food security (Saseendran et al., 1991, 2015).

Taro is a major root crop of the Araceae family and is widely distributed in the tropics and subtropics (Lebot, 2009). It is considered an undemanding plant regarding cultural practices, such as the use of fertilizers and pesticides (Gondim et al., 2007). Taro is also one of the least water-efficient crops (Uyeda et al., 2011, Daryanto et al., 2016). Both the quantity and distribution of the available water have a significant effect on taro growth, which may ultimately interfere with taro yield. The crop is fundamental to ensuring food security and rural development (Melese, 2017). Globally, taro is ranked the 14th most productive plant among staple crops, with a yield of approximately 12 million tons from approximately two million hectares of land (Rao et al., 2010).

However, little information is found on the water stress tolerance of taro under different soil types. Sivan (1995) developed a study focused on the breeding of more water-tolerant taro varieties and observed that stomatal conductance, leaf number (LN), and leaf area (LA) of two cultivars decreased in response to water stress. Sahoo et al. (2006) observed a significant reduction in LN and LA with an increase in water stress; conversely, the author reported a minimum reduction in yield. Uyeda et al. (2011) evaluated the response of taro varieties to five irrigation rates (50%, 100%, 150%, 200%, and 250% ET_0 - reference evapotranspiration) and found maximum taro yield at 150% ET_0 . Also, Mabhaudhi et al. (2013) tested the response of taro to three

water regimes based on crop water requirement (ET_c) to evaluate its growth, yield, and water-use efficiency. They found that LN and LA decreased by between 5% and 19% at 60% and 30% ET_c , respectively. In addition, taro yield was 15% and 46% higher at optimum irrigation (100% ET_c) when compared with 60% ET_c and 30% ET_c , whereas water-use efficiency (WUE) was relatively stable among water regimes.

The effects of soil texture on WUE are often neglected, even in the most recent studies on water-use efficiency (for some examples, check Tränkner et al., 2016; Ren et al., 2017; and Huang et al., 2017). Martin and Miller (1983) studied the response of potato yield to deficit irrigation under different soil textures (sandy and loam soil) and found that potato yield greatly increased in sandy soil with the increase in irrigation levels (from 0% to 70%-80% ET_0). Irrigation levels higher than 70% and 80% ET_0 had minimal effect, which is probably because sandy soil has a water-holding capacity lower than loam soil. Furthermore, Katerji and Mastrorilli (2009) observed a significant reduction (22%-25%) in WUE in clay soil for potatoes, corn, sunflowers, and sugar beets, comparing with that detected in loam soil.

Thus, the response of taro to varying water regimes and soil textures must be evaluated. Such information would allow more efficient application of agricultural water by improving and applying existing irrigation technologies. Therefore, this study aimed to evaluate the growth, yield, and water-use efficiency of taro under five water regimes (20%, 60%, 100%, 140%, and 180% ET_c) in three soil textures (clay, sandy clay loam, and sandy soil).

2.2 MATERIALS AND METHODS

Site and treatment description. The experiment was conducted from May 31, 2016 to March 1, 2017, in a greenhouse (7.0 × 30 × 6 m), in the experimental area of the Agronomical Sciences College, São Paulo State University (UNESP), Campus of Botucatu (22°51'S; 48°27'W), state of São Paulo, Brazil. During the experimental period, the average temperature was 21.0 °C, the average ET_0 was 3.56 mm/day, and the average air humidity was 62.1%, as shown in Table 2.1.

Table 2.1 Average maximum and minimum of temperature, air humidity, ET_0 and K_c in the greenhouse during the experiment period, São Paulo, Brazil.

Month/Year	ET_0 (mm/day)	K_c	Tmax (°C) ^a	Tmin (°C) ^b	Umax (%) ^c	Umin (%) ^d
July 2016	2.11	1.05	27.53	10.54	85.27	36.55
August 2016	2.68	1.05	28.19	13.22	79.94	38.48
September 2016	2.70	1.05	29.22	13.73	76.43	37.43
October 2016	3.28	1.15	27.77	16.57	82.06	36.26
November 2016	3.67	1.15	28.79	17.16	86.39	35.86
December 2016	3.44	1.15	29.01	18.14	86.73	33.00
January 2017	5.30	1.15	28.80	19.70	98.40	47.20
February 2017	5.30	1.10	29.20	18.40	96.10	37.10

^a Temperature maximum; ^b Temperature minimum; ^c Air humidity maximum; ^d Air humidity minimum.

A factorial experimental design was performed with two factors (irrigation level and soil type), replicated four times, with two plants per replication, for a total of 120 plants. Five irrigation levels (20%, 60%, 100%, 140%, and 180% ET_c) were applied, and 100% ET_c was used as the control. Three soil types (clay soil, sandy clay loam soil, and sandy soil) were used. The experiment was carried out in a randomized complete block design (Figure 2.1). Each pot (replication) had the capacity of 25 L, with a plant spacing of 0.6 m × 0.5 m (Figure 2.2 A).

Irrigation treatments began on August 18, 2016 (at 30 days after transplanting) and were applied daily, using drip irrigation. Two harvests were conducted, one on December 1, 2016 (at 135 days after transplanting), and another on March 1, 2017 (at 225 days after transplanting).

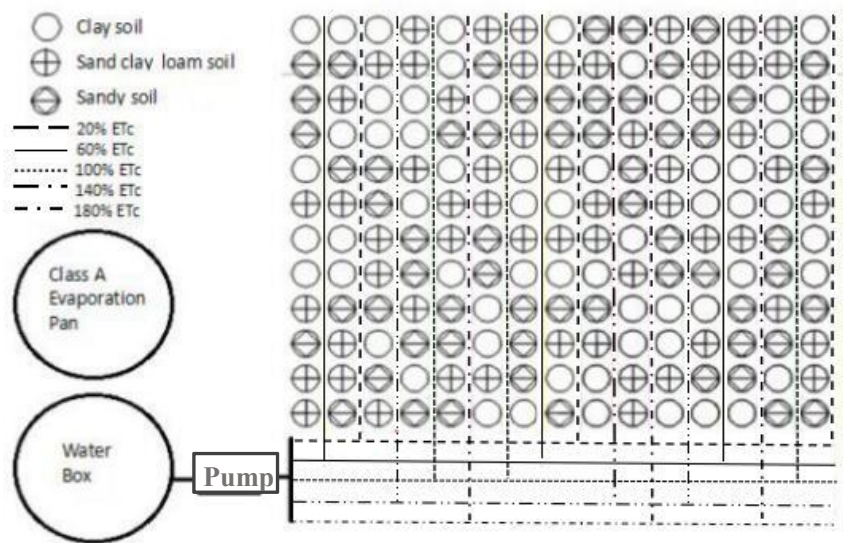


Figure 2.1 Experimental design.

Plant materials. The taro cultivar selected for evaluation was ‘Chinese’. Taro growth cycle has four physiological stages (Mare, 2009): dormancy, vegetative stage, reproductive stage, and maturity. Taro propagation for corms commercial exploitation is performed exclusively by planting the corm, which is the major commercial product (Puiatti, 2001). Before sowing, 400 corms weighing between 30g and 50g were selected for seedling preparation. They were sown in 400 mL plastic cups (with three holes at the bottom of the cup), which were filled with soil and substrate. With a soil to substrate ratio of 1:1 by volume. Sandy clay loam soil (SCL) was used as the soil. The substrate was suitable for tropical conditions and had the following characteristics: a moisture content of 60%, a water-holding capacity of 130% (both by weight), a bulk density of 200 kg m^{-3} , a pH of 5.8, and an electrical conductivity of 2.0 mS cm^{-1} . At 48 days after sowing, 120 seedlings with similar sizes (approximately three leaves per seedling) were selected and transplanted into the pots.

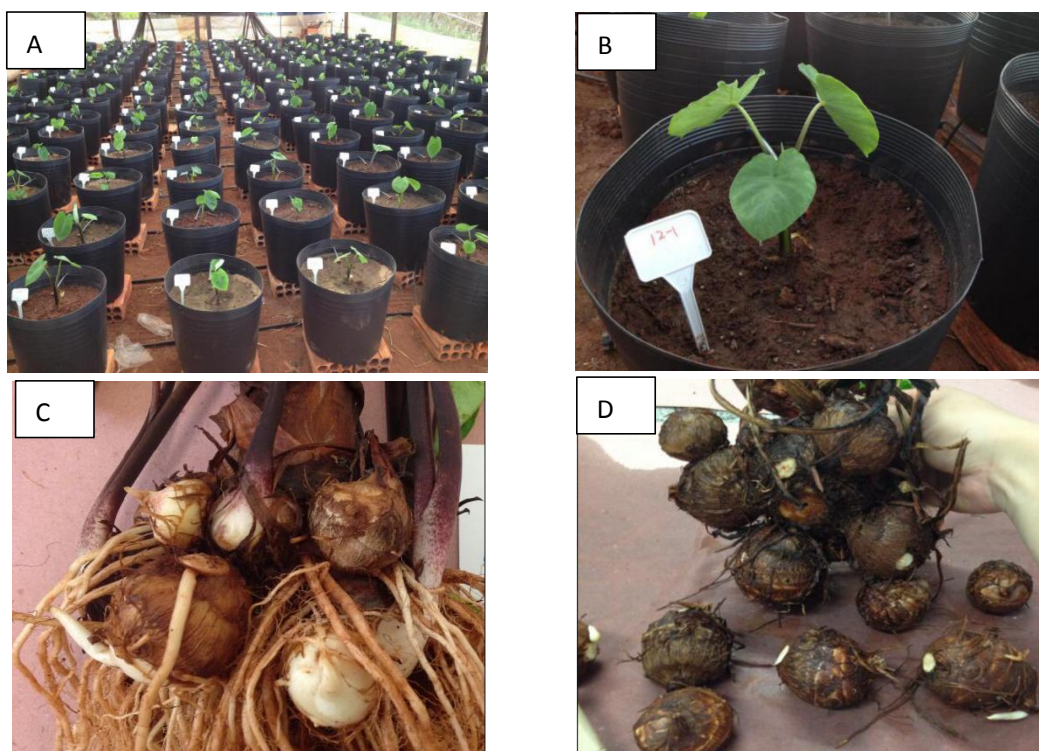


Figure 2.2 Taro in pot in the greenhouse and taro corms in harvests (“C” is the corm of first harvest, “D” is the corm of second harvest).

Soils. The three types of soil used in this study were collected from the arable layer, at the 0-20 cm depth, from the Agronomical Sciences College Farm, São Paulo State University, Campus of Botucatu (22°51’S; 48°27’W), state of São Paulo, Brazil. After collection, each soil sample was air-dried and sieved through a 2 mm mesh for soil fertility and texture analyses (Table 2.2). The pH (CaCl₂), organic matter (OM), P, H + Al, K, Ca, and Mg, SB (sum of bases), CEC (cation exchange capacity), and BS (base saturation, %) were determined according to the methodology described by Raij et al. (2001). The particle size was determined using the pipette method (EMBRAPA, 2006). Soil texture was classified according to FAO (2006).

Table 2.2 Textural and chemical characteristics of soils used in the experiment.

Textural class	Sand	Silt	Clay	pH	O.M	P _{resin} ^a	H+Al	K	Ca	Mg	SB	CEC	BS%
	g/Kg.....			CaCl ₂	g/dm ³	mg/dm ³			mmol/dm ³				
CS	436	108	456	3.9	14	5	87	0.5	3	1	5	92	5
SCL	652	57	291	4.1	16	4	77	0.7	3	1	4	81	5
SS	957	9	34	4.7	9	4	17	1.1	7	3	10	28	38

^a P resin is an method used for analysis of phosphorus in the soil. CS=clay soil;

SCL=sandy clay loam; SS=sandy soil.

Before transplanting, the pH of the three soil types was corrected using limestone. The acidity correction was calculated based on the need for liming to raise the base saturation of each soil to 60%, according to the recommendation of Bulletin 200 (Aguiar et al., 2014).

Based on soil fertility results and the recommendation of the Bulletin 200 (Aguiar et al., 2014), 200 mg L⁻¹ of P, 30 mg L⁻¹ of N, and 40 mg L⁻¹ of K (using triple superphosphate, urea, and potassium chloride, respectively) were applied to each pot before transplanting (soils were kept wet for fertilization). The amounts of corrective and fertilizer applied per pot, in grams, were calculated considering the pot capacity (25 L).

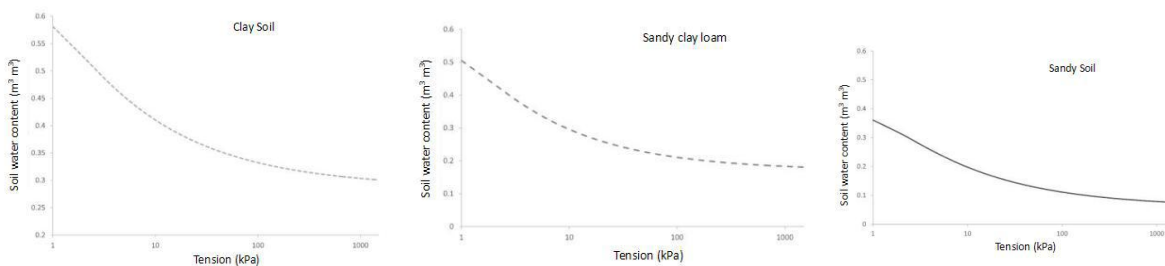


Figure 2.3 Tension of the three soils

Irrigation system. Irrigation was delivered using in-line pressure-compensating emitters, with a flow rate of 2.0 L h⁻¹, which were positioned on each pot using a microtube with a connector. The time of irrigation and the volume of water to be applied were determined by a simplified water balance, using the Class A Evaporation Pan method (CAEP; Peixoto et al., 2010), which is a standard used to measure the water evaporation.

Irrigation scheduling was based on the evaporation value of the CAEP, pan coefficient (K_p), and crop factor (K_c) associated with phenological stages (Allen et al., 1998). The evaporation value of the CAEP was determined using the method proposed by Allen et al. (1998). The evaporation value and pan coefficient (K_p) were applied to determine the ET_0 (Equation 2), which varies according to local climatic conditions. In the present study, the value of K_p was 1, as recommended by Prados (1986). The growth cycle of taro is of approximately seven months (Lebot, 2009). K_c values of taro were as described by Fares (2008), where $K_{c \text{ initial}} = 1.05$ (two months),

$K_{c \text{ med}} = 1.15$ (four months), and $K_{c \text{ late}} = 1.1$ (one month). Based on the values of K_c and ET_0 , ET_c (Equation 1) was calculated using the single crop coefficient approach, as described by Allen et al. (1998):

$$ET_c = ET_0 \times K_c \dots\dots\dots [1]$$

where: ET_c = crop water requirement, ET_0 = reference evapotranspiration, and K_c = crop factor; and

$$ET_0 = CAEP \times K_p \dots\dots\dots [2]$$

where: CAEP = Evaporation value of Class A Evaporation Pan, and K_p = Pan coefficient.

During the first month after transplanting, all treatments were irrigated with 100% ET_0 . Thereafter, irrigation treatments were imposed. Irrigation was performed every morning to ensure water availability during the peak periods of plant demand during the day. The last irrigation occurred on February 28, 2017. The total irrigation water applied (WU_t), taking the initial watering into account, ranged from 1580 mm (180% ET_c) to 1244 mm, 908 mm, 572 mm, and 236 mm for 140%, 100%, 60%, and 20% ET_c , respectively.

Data collection. LN and LA evaluations began at 15 days after transplanting. Data were collected once a month until the second harvest. Only fully-expanded leaves with at least 50% green leaf area were considered in the LN evaluation. The first harvest was conducted at approximately 19 weeks after transplanting, and the second harvest occurred at approximately 32 weeks after transplanting, during which the fresh weight of corms was recorded (Figure 2 B & C).

Leaf area was measured by the non-destructive method developed by Chapman (1964), which was adapted to the 'Chinese' taro by Nolasco et al. (1984), using the following equations:

$$Y = 242.0 \times X^{0.6656} \dots\dots\dots [3]$$

$$X = AA' \times AB \times AB' / 1000 \dots\dots\dots [4]$$

Where: AA' = distance from the insertion of the petiole to the extremity of the leaf blade, AB = distance from the right end of the leaf blade to the petiole insertion, and AB' = distance from the left end of the leaf blade to the petiole insertion.

Corm yield was calculated by summing the fresh weight of taro corms per plant (corms are shown in Figure 2 C and D), and WU_t was calculated by summing the daily

water applied. Water-use efficiency (WUE) was calculated according to the following equation (Mabhaudhia et al., 2013):

$$WUE = Y_c / WU_t \dots\dots\dots [5]$$

Where: WUE = water-use efficiency in kg m⁻³, Y_c = sum of the fresh weight of corms in kg, and WU_t = total water applied in m³.

Statistical analysis. Data (leaf number, leaf area, corm yield, and water-use efficiency) were subject to the analysis of variance (ANOVA), using the Sigmaplot® (Version 11.0, ISI, USA). The Tukey's Honest Significant Difference test (HSD) was used for multiple comparison tests, with a significance level of $\alpha = 0.05$.

2.3 RESULTS

Effects of water regime and soil texture on LN and LA of taro. Leaf number (LN) showed a highly significant difference ($p < 0.001$) between irrigation treatments (Figure 2.4 a, c, e), as well as between soil textures (Figure 2.5 a, c, e, g, i). The interaction between irrigation treatment and soil type was also significant ($p < 0.05$). Leaf number increased by 18% and 14% at 140% and 180% ET_c, respectively, and decreased by 3% and 44% at 60% and 20% ET_c, respectively, when compared with the control treatment (100% ET_c). In CS (clay soil) and SS (sandy soil), LN was slightly higher for 140% ET_c than 180% ET_c (Figure 2.4 a, e); conversely, for SCL (sandy clay loam), LN exhibited a consistent decline with a decrease in water regimes, although no statistically significant differences were detected between 60%, 100%, 140%, and 180% ET_c. LN for CS (6.09 plant⁻¹) and SCL (6.10 plant⁻¹) were similar, whereas LN for SS was 22% higher than that of the other soil types. LN was slightly higher for SCL when compared with that of CS at 20%, 60%, and 100% ET_c. On the other hand, LN for CS was higher than that of SCL at 140% and 180% ET_c. A closer look at the results showed that LN for SCL (6.98 plant⁻¹) at the maximum water regime (180% ET_c) was lower than that observed for SS at 60% ET_c (8.35 plant⁻¹). At lower water regimes (20%, 60%, and 100% ET_c), LN was slightly higher for SCL than for CS; conversely, LN was lower for SCL than for CS at higher water regimes (Figure 2.5 a, c, e). Overall, results showed that LN for SS was higher at all water regimes, comparing

with those of the other soil textures.

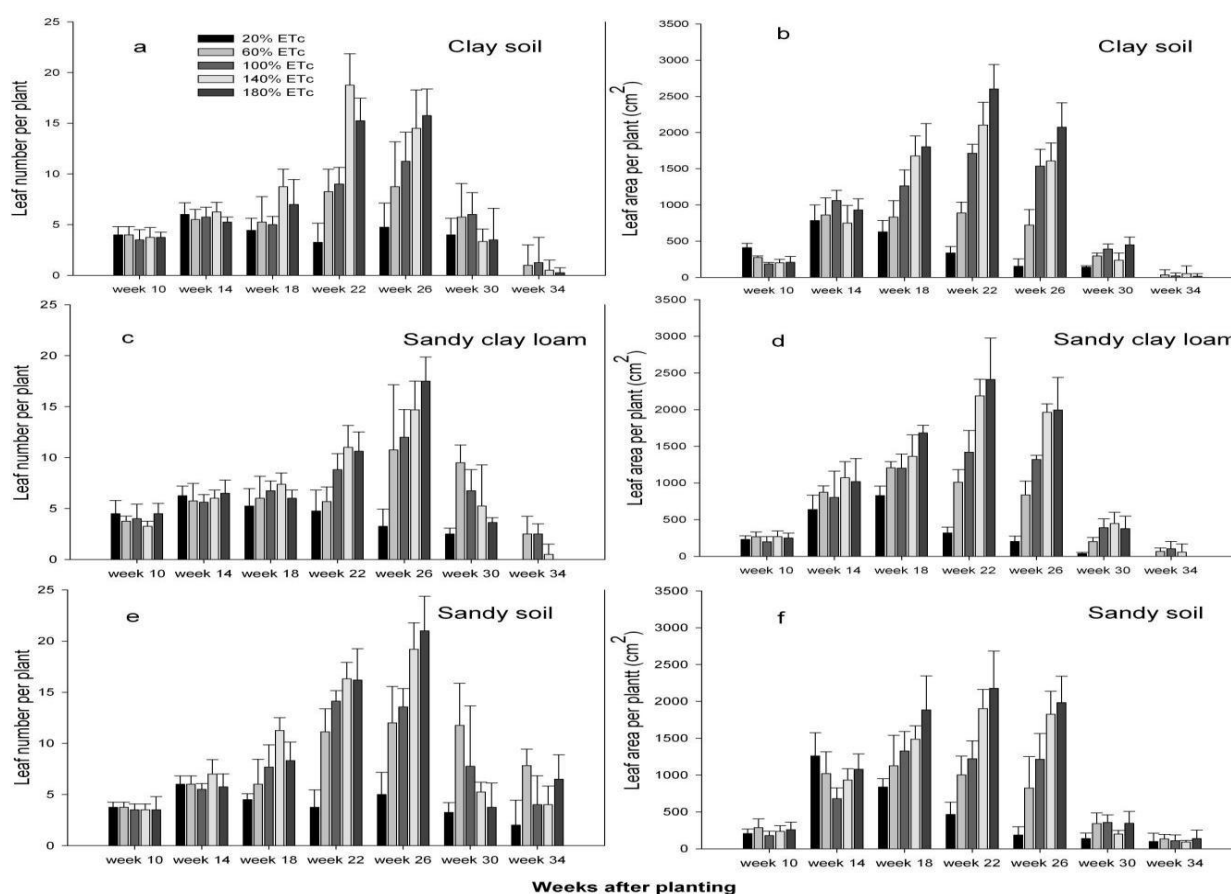


Figure 2.4 Response of taro leaf area (cm^2) and leaf number per plant by water regime.

Highly significant differences were observed for LA ($p < 0.001$) between irrigation treatments; however, no significant differences ($p > 0.05$) were detected between soil textures (Figure 2.5 b, d, f, h, j). The interaction between irrigation treatment and soil type was significant ($p < 0.05$). Leaf area decreased by 54% and 22% at 20% and 60% ET_c , respectively, and increased by 24% and 42% at 140% and 180% ET_c , respectively, when compared with 100% ET_c (Figure 2.4 b, d, f). Since LN showed the highest value at 140% ET_c , individual leaves were smaller when compared with those at 180% ET_c , which resulted in a smaller LA at 140% ET_c . Also, LA for SS was 42% and 30% higher than that of SCL and CS, respectively, at 20% ET_c . Conversely, at 100% ET_c , CS showed the highest LA among the three soil types. At 60%, 140%, and 180% ET_c , no statistically significant differences were detected between soil types

(Figure 2.5 d, h, j). Overall, LA showed to be significantly affected by changing the water availability in all types of soils; SS showed a higher LA regulation under limited water conditions when compared with SCL and CS. Nevertheless, LA was not significantly affected by soil types at higher water regimes.

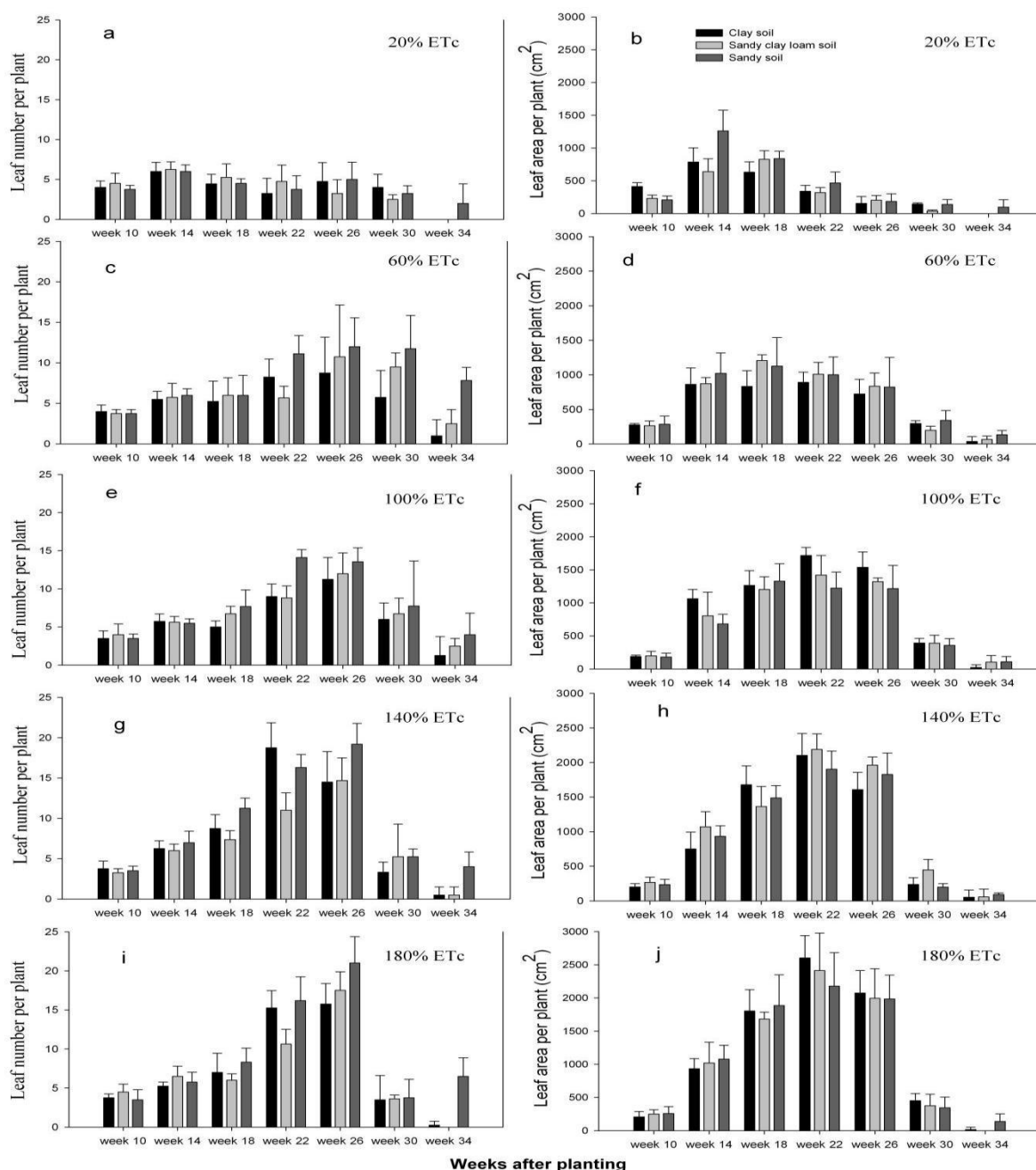


Figure 2.5 Response of taro leaf area (cm²) and leaf number per plant by soil texture.

Effects of water regime and soil texture on Y_c and WUE of taro. Y_c showed highly significant differences between water regimes ($p < 0.001$). In the first harvest,

Y_c of different water regimes exhibited the following trend: 140% ET_c > 180% ET_c > 100% ET_c > 60% ET_c > 20% ET_c . Conversely, in the second harvest, the trend was: 180% ET_c > 140% ET_c > 100% ET_c > 60% ET_c > 20% ET_c (Table 2.3). No significant differences were detected in Y_c among the soil types in the first harvest. However, a significant difference ($p < 0.05$) was observed in the second harvest. Y_c of SS was significantly higher than that of SCL and CS by 19% and 10%, respectively. Results of LN and LA revealed that SS was better for taro yield accumulation.

Table 2.3 Effects of water regime and soil texture on mean taro Y_c^{n} and WUE^{o} by harvest. Values in table are means ($n=4$).

Harvests	Water Regimes	WU_t^{m} (m^3)			Y_c (Kg)			WUE ($kg\ m^{-3}$)		
		Soil texture			Soil texture			Soil texture		
		CS	SCL	SS	CS	SCL	SS	CS	SCL	SS
First Harvest	20% ET_c	0.12	0.12	0.12	0.10aC ^a	0.13aD	0.12aD	0.83aA	1.10aA	1.04aA
	60% ET_c	0.36	0.36	0.36	0.18aC	0.20aCD	0.24aC	0.50aB	0.56aB	0.69aB
	100% ET_c	0.60	0.60	0.60	0.31aB	0.31aBC	0.38aAB	0.53aB	0.52aB	0.64aB
	140% ET_c	0.84	0.84	0.84	0.46aA	0.41aAB	0.46aA	0.56aB	0.50aB	0.55aB
	180% ET_c	1.08	1.08	1.08	0.41aA	0.45aA	0.36aB	0.39aB	0.42aB	0.34aC
Second Harvest	20% ET_c	0.25	0.25	0.25	0.11aE	0.11aD	0.16aD	0.44bA	0.44bA	0.64aA
	60% ET_c	0.61	0.61	0.61	0.25bD	0.27bC	0.34aC	0.38bA	0.45bA	0.55aAB
	100% ET_c	0.98	0.98	0.98	0.43aC	0.45aB	0.47aB	0.44aA	0.43aA	0.48aBC
	140% ET_c	1.34	1.34	1.34	0.53aB	0.50aAB	0.56aAB	0.40aA	0.35aA	0.42aC
	180% ET_c	1.70	1.70	1.70	0.69aA	0.60aA	0.65aA	0.40aA	0.35aA	0.39aC

^a Mean separation between water regimes within soil texture (capital letters) and between soil textures within water regime (lower case letters) by t-test at $\alpha = 0.05$; ^m Total water use; ⁿ Yield of corms; ^o Water-use efficiency.

Water-use efficiency (WUE) also showed highly significant differences ($p < 0.001$) between water regimes in both harvests; however, a highly significant difference ($p < 0.001$) between soil types was observed only in the second harvest (Table 2.3). For both harvests, the highest WUE was reported at 20% ET_c , and no statistically significant differences were observed in WUE among the four highest water regimes. In the second harvest, WUE for CS ($0.41\ kg\ m^{-3}$) and SCL ($0.40\ kg\ m^{-3}$) were similar, whereas WUE for SS was 22% higher than that of the other two soil textures (Table 2.3).

2.4 DISCUSSION

Results show that limited water availability (20% and 60% ET_c) reduced LN and LA (Figure 2.4). In contrast, over-irrigation (180% ET_c) could negatively influence LN, although it may be beneficial in increasing LA. The lower LN observed under limited water availability was consistent with reports of Mabhaudhi (2013) and Sahoo et al. (2006). Mabhaudhi (2013) documented 5% and 12% reduction in leaf area index (LAI) at 30% ET_c and 60% ET_c , respectively, when compared with that of 100% ET_c . The lower LA observed under limited water availability in the present study also corroborates the results of Sivan (1995), who observed reduced growth in taro subject to drought stress.

Leaf area (LA) and leaf number (LN) represent the canopy size, as well as the surface area available for transpiration (Mabhaudhi et al., 2013). Plants cope with reduced water availability by reducing the canopy size (Mitchell et al., 1998). Leaf area reduction has previously been ascribed to photosynthesis reduction under water-limited conditions (Anjum et al., 2011), which reduces leaf expansion. Additionally, LN reduction is caused by leaves premature senescence, which affects WUE. Hypothetically, a plant that shows a moderate reduction in the canopy size is capable of striking a balance between minimizing water loss and continuing reasonable biomass production (Blum, 2005, 2009). In this regard, SS was efficient in achieving both aspects. Although the crop canopy size reduced under water-limited conditions, it was more moderate in SS when compared with that of CS and SCL, resulting in a higher yield in SS than in the other two soil textures.

The response of Y_c to the irrigation applied (WU_t) in the present study is similar to that recently reported by Uyeda et al. (2011), Mabhaudhi et al. (2013), and Vieira et al. (2015). The authors stated that Y_c of taro decreased with a reduction in the applied irrigation. In addition, Daryanto et al. (2016) performed a meta-analysis on the effects of drought on root and tuber production, and their results indicated that taro generally suffered a greater production loss under water deficit conditions. Furthermore, Uyeda et al. (2011) found that while 150% ET_0 could maximize taro yield, increasing the irrigation level up to 250% ET_0 did not result in a higher yield. Therefore, determining

whether the increase in yield is worth the increase in water cost is fundamental, and SS may be an option to improve taro Y_c with less water application.

The trend of WUE in the present study (Table 2.3) was inconsistent with the reports of Bussell and Bonin (1998), who found WUE to be generally higher at high watering-level treatments than at low water-level treatments. Vieira et al. (2015) found that an increase in the applied water depth resulted in an increase in WUE to a maximum value of 2.78 kg m^{-3} at 75% ET_c . However, they also found a decrease in WUE at higher water regimes (100% and 125% ET_c). Additionally, drought has been shown to increase WUE in peanuts (Aranyanak et al., 2008), cassava (Olanrewaju et al., 2009), common beans, green gram (Webber et al., 2006), and Jerusalem artichokes (Janket et al., 2013). A reduction in WU_t should increase WUE and ultimately improve yield (Blum, 2005; Jones, 2004). A reduction in the canopy size (lower LN and LA) in response to the limited water availability is an attribute of increased WUE; however, this reduction should not be excessive since canopy size is directly correlated with reduced biomass production and yield (Blum, 2005, 2009). In the present study, soil texture influenced WUE in the second harvest; WUE was significantly lower in CS and SCL than in SS (Table 2.3). According to Katerji and Mastorilli (2009), soil texture can affect the WUE of potatoes, considering that heavier soil textures decrease WUE. The positive effect of SS on WUE recognized by Turner (2004) was confirmed in the present study for taro and was evident in the second harvest (Table 2.3). WUE was higher for SS at lower water regimes, indicating that it is probably wiser to improve WUE of taro by correctly choosing the soil type before increasing the irrigation water unilaterally.

2.5 CONCLUSION

The reasonable control of the irrigation applied and the correct selection of the soil type are key factors that need to be considered for taro production. These facts would help improve water-use efficiency and possibly yield. The present research showed the reduced canopy size (leaf number and leaf area) of taro under conditions of limited water availability. The reduction in the canopy size was greater for clay and

sandy clay loam soil than sandy soil, especially at lower water regimes for leaf area. Furthermore, canopy size and corm yield increased by increasing water regimes in all the soil textures. The highest water-use efficiency was observed at 20% ET_c, whereas no statistically significant differences were detected between 60%, 100%, 140%, and 180% ET_c in both harvests. Sandy soil showed to have significantly higher water-use efficiency and corm yield in the second harvest, suggesting that, under conditions of limited water availability, taro may be better adapted to sandy soils.

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CHAPTER 3 CHEMICAL COMPOSITION AND DRY BIOMASS OF TARO RESPONSE TO VARYING WATER REGIMES AND SOIL TEXTURES

Meiling Li¹; Angélica Cristina Fernandes Deus²; and Lin Chau Ming³

¹ MS., Department of Horticulture, Agronomical Sciences College, São Paulo State University, José Barbosa of Barros Street, 1780. Zip-Code: 18.610-307 - Botucatu, SP, Brazil. Email: lilmeilinghappy@outlook.com. Corresponding author.

²Post Doc., Department of Soil and Environmental Resources, Agronomical Sciences College, São Paulo State University, José Barbosa of Barros Street, 1780. Zip-Code: 18.610-307 - Botucatu, SP, Brazil.

³ Prof., Department of Horticulture, Agronomical Sciences College, São Paulo State University, José Barbosa of Barros Street, 1780. Zip-Code: 18.610-307 - Botucatu, SP, Brazil.

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ABSTRACT

The chemical composition and dry mass accumulation of taro (*Colocasia esculenta* L. Schott) response to water regime and soil texture were investigated in the present study. For this aim, an experiment with five water regimes (20%, 60%, 100%, 140% and 180% ET_c - crop water requirement) and three soil textures (clay, sandy clay loam, and sandy soil) was conducted in a greenhouse. Results showed that corm humidity (CH), above-ground dry weight (ADW), root dry weight (RDW), and corm dry weight (CDW) of taro corm increased with increase in water regime. Generally, reducing sugars (RS), and starch content (SC) showed a increased trend with increase in water regime, while the different trend was observed in total soluble solids (TSS) and total titratable acidity (TTA) in taro corm. However, TTA in taro leaf was increased with increase in water regime. In addition, protein content (PC) of taro corm was higher at 20% and 60% ET_c relative to 100% ET_c, while 140% ET_c and 180% ET_c showed lower PC, compared with 100% ET_c. In taro corm, sandy soil (SS) exhibited higher TSS, TTA, RS, SC, total sugars (TS), and CDW, while higher RDW was observed in SCL. CH was 6.2% higher in clay soil (CS), compared with sandy clay loam (SCL) and SS, while it was relatively constant (64%) in the latter two soils. In addition, a higher TTA

was also observed in SS in taro petiole. Overall, results reported in the present study suggested that higher water regime was more beneficial to improve corm quality, and SS could be more suitable for taro cultivation under water stress.

Keywords: Irrigation, Soil type, Corm quality, Water stress, Tuber.

3.1 INTRODUCTION

Colocasia esculenta is popularly known as "taro" and belongs to the Araceae family (Castro et al., 2017). As a tuber crop largely produced for its underground corm, it is mainly consumed in the tropical and sub-tropical countries (Matthews et al., 2017). The plant performs well with a temperature between 21 and 27°C and 1500-2000 mm of rainfall and does best in a soil with a pH of 5.5-6.5 and a moderate clay content (Onwueme, 1999).

The chemical composition of taro corm has been well documented by previous researches (Onwueme, 1978; Kaushal et al., 2015). It has a broader complement of nutrients than other tuber crops (Kaushal et al., 2015; Filho et al., 1997), it is superior to potatoes (*Solanum tuberosum*), sweet potatoes (*Ipomoea batatas*), cassava (*Manihot esculenta*) and yam (*Dioscorea* L.). In addition, the nutritional compounds of its corm vary significantly between cultivars and the differences are also well known from consumers and traders (Alcantara et al., 2013). There is also a variation between the proximal, central and distal parts of taro corm according to the chemical analyses complex (Mergedus, 2015; Kristl et al. 2016).

However, the chemical composition research of taro is still suffering from the lack of scientific information in relation with water regime and soil texture, in spite of that some researchers focused on the effect of variety, harvest interval and drying methods on chemical composition of taro corm (see, for example, Arıcı et al. 2016; Lebot et al. 2017; Castro et al. 2017; Kaensombath et al. 2012). It was recorded that the variations in CH (55.8% to 74.4%), SC (20.0% to 35.1%), and PC (0.5% to 2.1%) between taro cultivars (Agbor-Egbe and Rickard, 1990). Kaensombath et al. (2012) reported that effects of harvesting intervals on the chemical composition of taro leaf differed little. In addition, the storage temperature influences the quality of harvested

commodities (Kader and Rolle, 2004). Low storage temperature leads to developing more RS and decreasing SC of corm; while high storage temperatures, on the other hand, causes sprouting and weight loss (Pal et al., 2008).

Some researchers investigated the effect of water stress on the growth of taro (Sivan et al., 1995; Sahoo et al., 2006; Uyeda et al., 2011; Mabhaudhi et al., 2013), however, they mainly focused on taro water-use efficiency, corm yield and canopy size. Miller and Martin (1987) compared the response of potato to irrigation treatment under sandy and loam soil. They reported that in sandy soil, daily irrigation increased corm yield, number of corms, but decreased average corm weight, compared to irrigation every four days. While the responses to water regime were small in loam soil. In another work published by them which studied the response of potato yield and quality to irrigation treatment in sandy soil, they reported that irrigation treatment had no effect on the number of corms, the yield reduction of potato was due largely to reduced corm size (Miller and Martin, 1987).

Thereby, there is a need to evaluate the response of chemical composition of taro to water regime and soil texture. The aim of the present study was to evaluate the response of pH, TSS, TTA, CH, TS, RS, SC, and PC of taro to five water regimes and three soil textures.

3.2 MATERIALS AND METHODS

Site description and meteorological conditions. The experiment was carried out in the experimental area of Agronomical Sciences College, São Paulo State University (UNESP), Botucatu (22°51'S; 48°27'W), São Paulo, Brazil. The taro was grown in a greenhouse with dimensions of 7.0 x 30 x 6.0 m, from May 31, 2016 to December 1, 2016. This region has a subtropical climate with the average temperature during the experimental period was 21.0°C, the average ET_0 was 2.98 mm/day, and the average air humidity was 59.5 % as shown in Table 3.1.

Table 3.1 Average maximum and minimum of temperature, air humidity, and ET_0 in the greenhouse during the experiment period, São Paulo, Brazil.

Month/Year	ET_0 (mm/day)	K_c	Tmax (°C) ^a	Tmin (°C) ^b	Hmax (%) ^c	Hmin (%) ^d
July 2016	2.11	1.05	27.53	10.54	85.27	36.55
August 2016	2.68	1.05	28.19	13.22	79.94	38.48
September 2016	2.70	1.05	29.22	13.73	76.43	37.43
October 2016	3.28	1.15	27.77	16.57	82.06	36.26
November 2016	3.67	1.15	28.79	17.16	86.39	35.86
December 2016	3.44	1.15	29.01	18.14	86.73	33.00

^a Temperature maximum; ^b Temperature minimum; ^c Air humidity maximum; ^d Air humidity minimum.

Experimental design and plant materials. The experiment was conducted according to the randomized complete block design (Figure 3.1) with two factors (irrigation level and soil texture). Five water regimes (20%, 60%, 100%, 140%, and 180% ET_c) and three soil types (clay soil, sandy clay loam soil, and sandy soil) were applied, and 100% ET_c was used as the control. Replicated four times, for a total of 60 plants. The taro was grown in the pot, each of which had the capacity of 25 L, with a plant spacing of 0.6 m × 0.5 m (Figure 3.2). In the experiment, the taro cultivar selected for investigation was ‘Chinese’. It has four physiological stages for growth cycle (Mare, 2009): dormancy, vegetative stage, reproductive stage, and maturity.

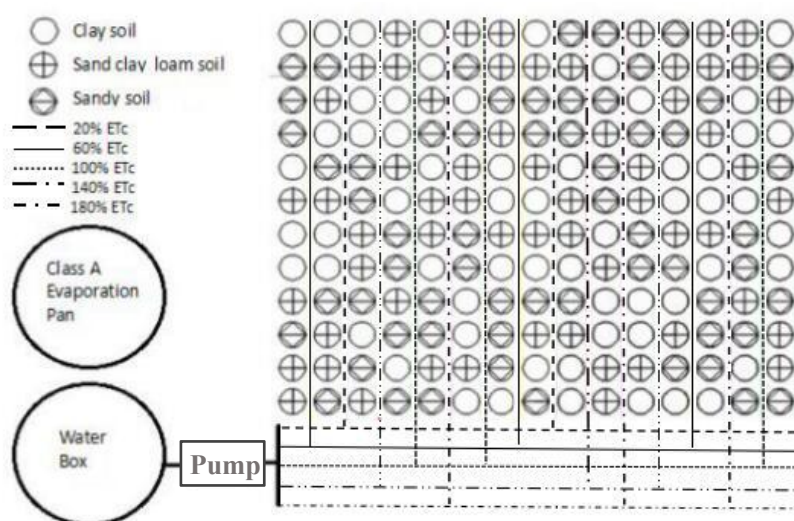


Figure 3.1 Experimental design.

Taro propagation. The taro was rapidly propagated vegetatively (Puiatti, 2001)

with 400 corms weighing between 30g and 50g for seedling propagation. They were sown in 400 mL plastic cups (with three holes at the bottom of the cup), which were filled with soil and substrate. With a soil to substrate ratio of 1:1 by volume. Sandy clay loam soil (SCL) was used as the soil. The substrate was suitable for tropical conditions. At 48 days after sowing, 60 seedlings with similar sizes (approximately three leaves per seedling) were selected and transplanted into the pots.

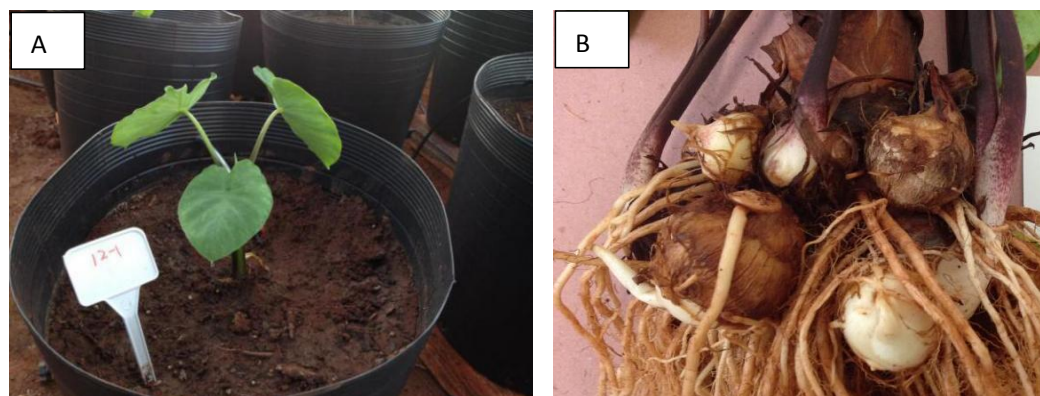


Figure 3.2 Taro in pot in the greenhouse (A) and taro corms in harvest (B).

Preparation of soils, organic compost, and water. The soils used in the current investigation were collected from the Agronomical Sciences College Farm, São Paulo State University, Botucatu, São Paulo, Brazil. The three soils were taken from the depth of 0-20 cm. The determination of the content of sand, silt, and clay in the three soil samples was performed by pipette technique (EMBRAPA, 2006), whereas their textural class was defined according to FAO (2006). The chemical characteristics of soils were determined according to the methodology described by Raji et al. (2001). Soil analysis results are shown in Table 3.2.

Table 3.2 Textural and chemical characteristics of soils used in the experiment.

Textural class	Sandg/Kg.....	Silt	Clay	pH CaCl ₂	O.M g/dm ³	P _{resin} ^a mg/dm ³	H+Al	K	Ca	Mg	SB	CEC	BS%
CS	436	108	456	3.9	14	5	87	0.5	3	1	5	92	5
SCL	652	57	291	4.1	16	4	77	0.7	3	1	4	81	5
SS	957	9	34	4.7	9	4	17	1.1	7	3	10	28	38

^a P resin is an method used for analysis of phosphorus in the soil.

According to Bulletin 200 (Aguiar et al., 2014), the pH of the three soils was

corrected using limestone before transplanting. The acidity correction was calculated based on the need for liming to raise the base saturation of each soil to 60%. Based on the analysis of the soils and the recommendation of Bulletin 200 (Aguilar et al., 2014), 200 mg L⁻¹ of P, 30 mg L⁻¹ of N, and 40 mg L⁻¹ of K (using triple superphosphate, urea, and potassium chloride, respectively) were applied to each pot. The amounts of corrective and fertilizer applied per pot, in grams, were calculated considering the pot capacity (25 L).

During the experiment period, compost heap was done twice (in September and December of 2016, respectively), 1.5 L of organic compost was applied above the soil per pot. The irrigation water resource was from Sabesp, State of São Paulo, Brazil. According to the chemical characteristics of the irrigation water, it was classified as C1S1 (Richards, 1954), and does not show restriction for irrigation. Organic compost and water analysis results are shown in Table 3.3 and Table 3.4, respectively.

Table 3.3 Chemical characteristics of organic compost used in the experiment.

		O.M	N	P ₂ O ₅	K ₂ O	Ca	Mg	S	U-65°C	C	Na	Cu	Fe	Mn	Zn
pH	C/N	 %								 mg/Kg					
7.7	11/1	34	1.8	1.4	0.6	1.8	0.4	0.3	13	19	609	63	10005	348	120

Table 3.4 Chemical characteristics of water used in the experiment.

	N	P	K	Ca	Mg	S	Na	B	Cu	Fe	Mn	Zn	C.E
pH	 mg/L												μS/cm
7.3	4	1	22	18	10	5	3.80	0	0	0.16	0	0	73

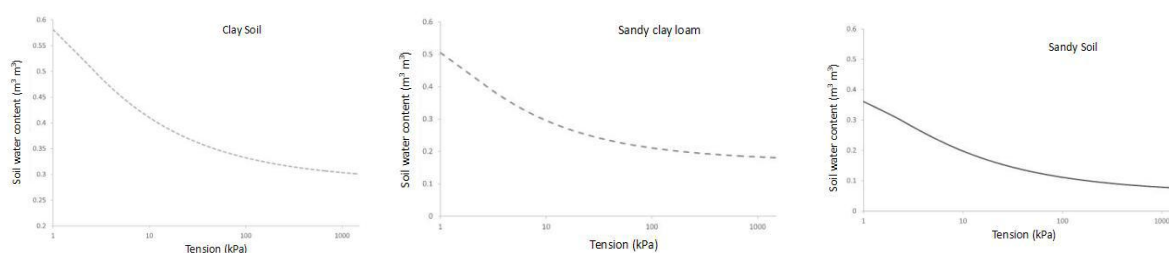


Figure 3.3 Tension of the three soils

Irrigation system. The irrigation system used was drip irrigation, which was delivered using in-line pressure-compensating emitters, with a flow rate of 2.0 L h⁻¹. It is connected by a 4 mm microtube on lateral line (16 mm) and branch line (25 mm). The system is pressurized by an irrigation pump (0.5 HP of power) and a gauge height of 30 mca. The time of irrigation and the volume of water to be applied were

determined by using the Class A Evaporation Pan method (CAEP; Peixoto et al., 2010).

Irrigation management was based on reference evapotranspiration (ET_0) and a crop factor (K_c) (Allen et al., 1998). The ET_0 was obtained from the values of CAEP and pan coefficient (K_p) (Equation 2), which varies according to local climatic conditions. In the current investigation, the value of K_p was 1, according to Prados (1986). The growth cycle of taro is of approximately seven months (Lebot, 2009). The K_c values of taro were: $K_{c \text{ initial}} = 1.05$ (two months), $K_{c \text{ med}} = 1.15$ (four months), and $K_{c \text{ late}} = 1.1$ (one month), respectively, as described by Fares (2008). Based on the K_c and ET_0 , ET_c (Equation 1) was calculated using the single crop coefficient approach, as described by Allen et al. (1998):

$$ET_c = ET_0 \times K_c \dots\dots\dots [1]$$

where: ET_c = crop water requirement, ET_0 = reference evapotranspiration, and K_c = crop factor; and

$$ET_0 = CAEP \times K_p \dots\dots\dots [2]$$

where: CAEP = Evaporation value of Class A Evaporation Pan, and K_p = Pan coefficient.

At the beginning of the study, all treatments were irrigated with 100% ET_0 . One month after transplanting, irrigation treatments were imposed. Irrigation was applied during the mornings to ensure water availability during peak periods of demand in the day. The last irrigation occurred on November 30, 2016. Taking into consideration the initial watering, the total actual amount of water applied (WU_t) was ranged from 946 mm (180% ET_c) to 751 mm, 556 mm, 360 mm and 165 mm for 140%, 100%, 60%, and 20% ET_c , respectively.

Data collection. The harvest was conducted approximately 135 days after transplanting. In the harvest, pH, total soluble solids (TSS), and total titratable acidity (TTA) were determined in taro corm, leaf, and petiole. pH of homogenized extracts of taros was measured using the Digimed DMPH-2 potentiometer, as recommended by Adolfo Lutz Institute (1985). For TSS determination, the juice extracted from a slice of the corm was used, then it was placed on the prism of an electronic refractometer; The ° Brix was then read directly by ABBE refractometer, brand ATAGO - N1, according to the recommendations by A.O.A.C (1970). To determine TTA, 5g of fresh

taro were used and diluted in 95 mL of deionized water. The titration was performed with a standard solution of 0.1 N sodium hydroxide and the indicator used was phenolphthalein (Adolfo Lutz Institute, 1985). The results were expressed as percent of malic acid.

Total sugars (TS), reducing sugars (RS), starch content (SC), protein content (PC), and corm humidity (CH) were determined in taro corm. TS and RS obtained by alcohol extraction, according to Instituto Adolfo Lutz, which was quantified by spectrophotometry with Somogyi-Nelson reagents, at 500 nm wavelength, in Spectrum 70 Bausch & Lomb apparatus, as described by Aued et al. (1989). The SC was determined on the residue of the alcoholic extract after hot acid hydrolysis by the Lane-Eynon method, with the Fehling reagent, according to Instituto Adolfo Lutz procedure. For PC, the micro Kjeldahl method was used to estimate the total nitrogen, using the factor 6.25 to convert it into protein content, according to A.O.A.C (1970). CH was determined by greenhouse gravimetric method at 105°C, as described by Instituto Adolfo Lutz. The above-ground, root and corm of taro was dried at 105°C until the constant weight, and the above-ground dry weight (ADW), root dry weight (RDW), and corm dry weight (CDW) were calculated by summing its dry weight per plant.

Statistical analysis. Analysis of variance (ANOVA) was used to statistically analyze data (pH, total soluble solids, total titratable acidity, total sugars, reducing sugars, starch content, and protein content, corm humidity, above-ground dry weight, root dry weight, and corm dry weight) using Sigmaplot® version 11.0 (ISI, San Jose, California USA). The Tukey's Honest Significant Difference test (HSD) was used for multiple comparison tests, with a significance level of $\alpha = 0.05$.

3.3 RESULTS

Effects of water regime and soil texture on pH, total soluble solids (TSS), total titratable acidity (TTA) of taro corm, leaf, and petiole. pH demonstrated a statistically significant difference between water regimes for taro corm ($p = 0.03$) and leaf ($p = 0.003$). The lowest pH was obtained at 60% ET_c, on average, 6.4 and 6.2, respectively, for corm and leaf (Figure 3.4 a, b), whereas there was no significant

difference between the other irrigation treatments. No significant difference ($p > 0.05$) was observed between soil textures in its corm, leaf or petiole. With respect to soil texture, the average pH was 6.5, 6.3, and 6.1, respectively, for corm, leaf, and petiole (Figure 3.5 a, b, c).

For total soluble solids (TSS), the interaction between irrigation treatment and soil texture was significant in taro corm ($p < 0.001$) and petiole ($p = 0.033$). In taro corm, TSS was higher at 60% ET_c (7.5%) and 100% ET_c (7.0%) in SCL, whereas 20% ET_c and 140% ET_c showed higher TSS in SS, and there was no significant difference between water regimes in CS (Figure 3.4 d); With respect to soil texture, at 140% and 180% ET_c , SCL was observed to have significantly lower TSS compared with SS and CS; while at 20% ET_c , TSS was significantly higher (8.28%) in SS (Figure 3.5 d). For petiole, SS showed the highest TSS (5.4%) at 140% ET_c (Figure 3.4 f), and there was no significant difference among the other treatments. No significant differences were detected between water regimes ($p = 0.847$) or soil textures ($p = 0.499$) for TSS in taro leaf (Figure 3.4 e and Figure 3.5 e).

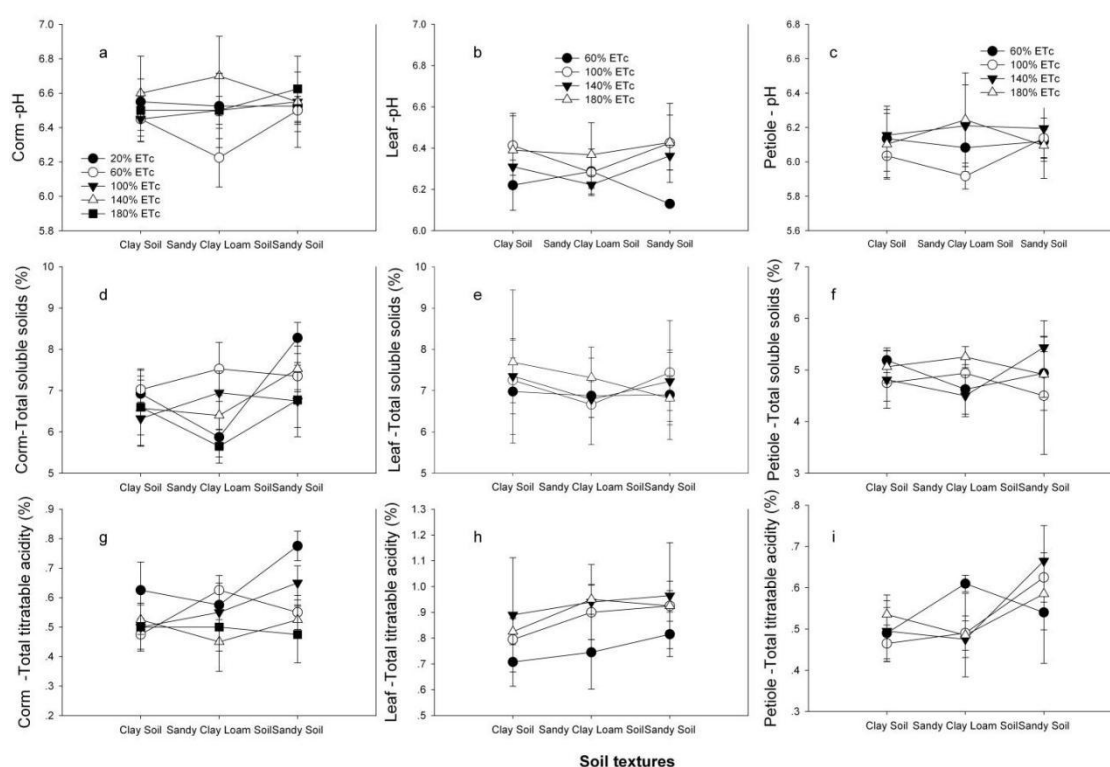


Figure 3.4 Response of pH, TSS, TTA of taro corm, leaf, and petiole to varying water regimes.

The interaction between irrigation treatment and soil type was significant for total titratable acidity (TTA) in taro corm ($p = 0.005$, Figure 3.3 g and Figure 3.4 g) and petiole ($p = 0.020$, Figure 3.4 i and Figure 3.5 i). In taro corm, water regime of 20% ET_c was observed to have the highest TTA, 0.62% and 0.78%, respectively, in CS and SS; whereas 60% ET_c showed the highest TTA in SCL (Figure 3.4 g). At 60% ET_c , SCL showed higher TTA (0.62%), while SS exhibited a higher TTA, 0.78% and 0.65%, respectively, at 20% and 100% ET_c (Figure 3.5 g). In taro petiole, SS showed highest TTA at 100% ET_c (0.6%) and 140% ET_c (0.7%), no significant difference was observed among the other treatments (Figure 3.5 i). While for taro leaf, a significant difference ($p = 0.008$) was observed between water regimes (Figure 3.4 h). The lowest TTA (0.8%) was observed at 60% ET_c , there were no significant differences among the other irrigation and soil treatments (Figure 3.4 h and Figure 3.5 h).

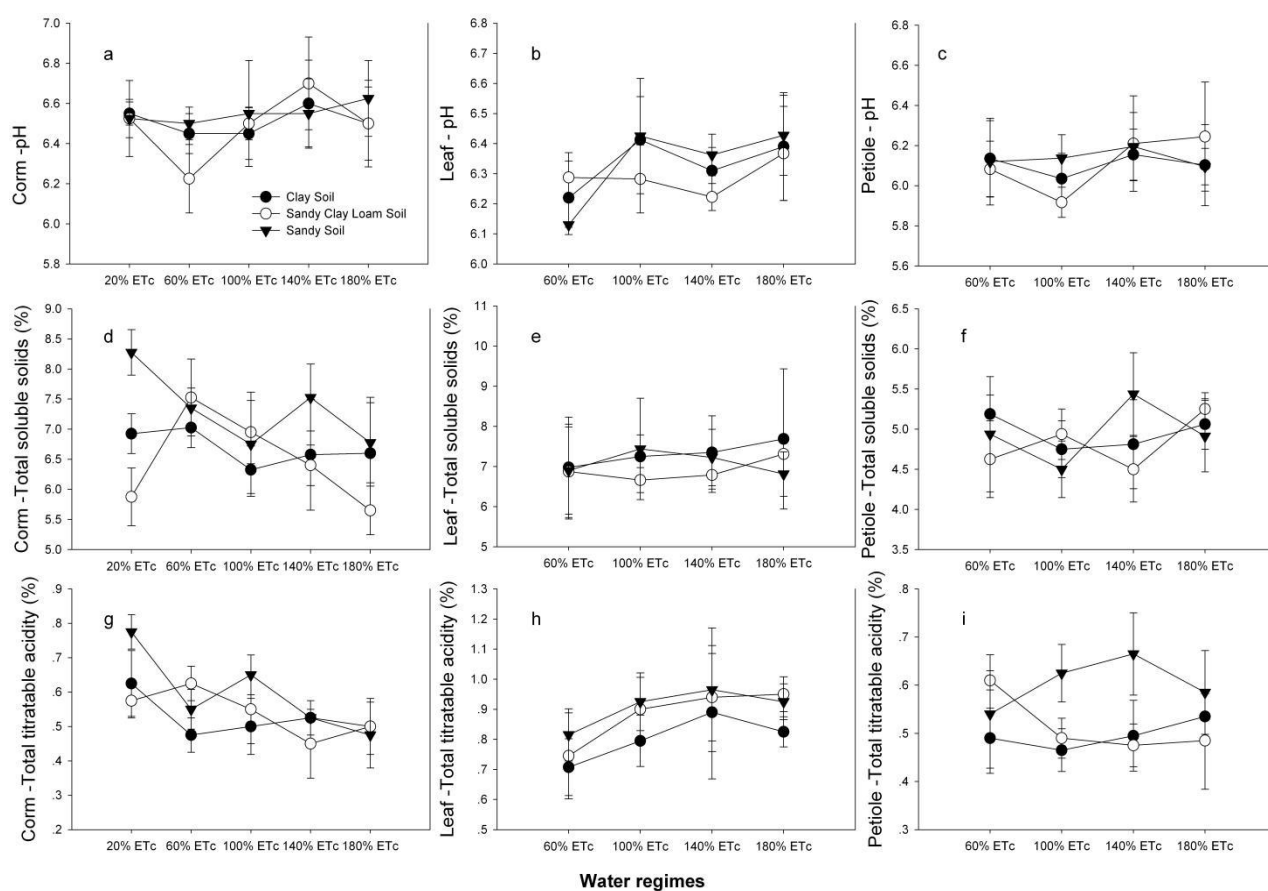


Figure 3.5 Response of pH, TSS, TTA of taro corm, leaf, and petiole to varying soil textures.

Effects of water regime and soil texture on chemical composition of taro corm. Significant differences ($P < 0.05$) were observed between irrigation treatments as well as between soil textures for total sugars (TS). The trend observed was $140\% ET_c > 60\% ET_c > 180\% ET_c > 20\% ET_c > 100\% ET_c$ (Table 3.5). On average, TS of CS (2.20%) and SCL (2.15%) was similar, while it was 18% lower compared with that of SS. Reducing sugars (RS) was shown to be significantly influenced by irrigation treatment as well as by soil type (Table 3.5). The interaction between irrigation treatment and soil type was also significant ($P < 0.001$). In the three soil types, RS showed an obvious decline at $20\% ET_c$, compared with the other water regimes (Table 3.5). However, there was no consistent increase with an increase in water availability from $60\% ET_c$ to $180\% ET_c$. In SCL, $180\% ET_c$ showed higher RS in comparison with that of $100\% ET_c$, whereas no significant difference was observed between $100\% ET_c$ and $180\% ET_c$ in CS and SS. With respect to soil texture, at 20% and $100\% ET_c$, SCL had significantly lower RS compared with CS and SS; At $60\% ET_c$, RS for SS was 16% and 17% lower, respectively, in comparison with CS and SCL. In addition, at $140\% ET_c$, CS showed lower RS compared with the other two soil types; Whereas at $180\% ET_c$ there was no significant difference in RS between soil textures. Overall, results pointed to SS having higher sugar accumulation in response to water stress.

Starch content (SC) of taro corm was significantly influenced by irrigation treatment as well as by soil texture (Table 3.5). There was also a significant difference ($P < 0.001$) of the interaction between irrigation treatment and soil texture (Table 3.5). In CS and SCL, $20\% ET_c$ showed lower SC in comparison with 60% , 100% , and $140\% ET_c$, whereas in SS, $100\% ET_c$ was observed to have the lowest SC, followed it was $20\% ET_c$. In addition, at $100\% ET_c$, SC of SS was 30% and 13% lower than that of CS and SCL, respectively. At 20% , 60% , and $180\% ET_c$, SS was observed to have the highest SC, compared with CS and SCL.

In line with the observations of protein content (PC) of taro corm, significant ($p < 0.001$) differences were observed between irrigation treatments (Table 3.5). Generally, PC was increased with decrease in water availability (see, for example, $140\% ET_c <$

180% ET_c < 100% ET_c < 60% ET_c < 20% ET_c). Whereas 180% ET_c showed slightly higher (6% higher) PC compared with that of 140% ET_c, however, it was lower than that of the other three irrigation treatments (20%, 60%, and 100% ET_c). No significant differences were observed for PC between soil textures (Table 3.5).

Table 3.5 Effect of water regime and soil texture on chemical composition of taro corm.

Values in table are means (n=4).

Water regime	Total sugars (%)			Reducing sugars (%)			Starch content (%)			Protein content (%)		
	Soil texture			Soil texture			Soil texture			Soil texture		
	CS	SCL	SS	CS	SCL	SS	CS	SCL	SS	CS	SCL	SS
20% ET _c	2.0Bb ^a	2.0BCb	2.5Ba	0.39Ca	0.30Cb	0.44Da	17Cb	17Cb	21Ca	2.8Aab	3.0Aa	2.7Ab
60% ET _c	2.4Aa	2.3ABa	2.6Ba	0.62Aa	0.63Aa	0.52Cb	20Bb	19Bb	26Ba	1.8Bc	2.0Bb	2.3Ba
100% ET _c	2.3ABa	1.7Cb	2.4Ba	0.62Aa	0.49Bb	0.69Aa	23Aa	22Aa	16Db	1.8Ba	1.7CDa	1.9Ca
140% ET _c	2.1ABc	2.4Ab	3.1Aa	0.52Bb	0.60Aa	0.59BCa	20Bb	23Aab	25Ba	1.7Ca	1.5Da	1.7CDa
180% ET _c	2.4Aa	2.3ABa	2.4Ba	0.62Aa	0.61Aa	0.64ABa	19BCb	18BCb	29Aa	1.8BCa	1.8Ca	1.7Da

CS = clay soil; SCL = sandy clay loam; SS = sandy soil. ^a Mean separation between water regimes within soil texture (capital letters) and between soil textures within water regime (lower case letters) by t-test at $\alpha = 0.05$.

Effect of water regime and soil texture on dry biomass accumulation of taro.

Highly significant differences were observed between water regimes for above-ground (ADW, $p < 0.001$), root (RDW, $p < 0.001$), and corm dry weight (CDW, $p < 0.001$) of taro (Table 3.6). Which were increased constantly with the increase in water regime (Table 3.6). Soil texture had no significant effect on ADW, whereas it influenced significantly on RDW ($p = 0.041$) and CDW ($p = 0.011$). SCL showed the highest RDW (22g plant⁻¹, on average), while for CDW, SS exhibited the highest value (56g plant⁻¹, on average). The interaction between irrigation treatment and soil type was significant for corm humidity the interaction ($p = 0.017$). The variation of CH was ranged from 41% to 78% (Table 3.6). And a trend of decline with decrease in water availability was observed in the three soil textures. It was decreased by 39% and 9% at 20% ET_c and 60% ET_c, respectively, relative to 100% ET_c. There was a significant difference for CH between soil textures at 100% ET_c, CS showed slight higher CH than that of SCL and SS (Table 3.6).

Table 3.6 Effects of water regime and soil texture on corm humidity, above -ground, corm, and root dry weight of taro. Values in table are means (n=4).

Water regime	Above-ground dry weight (g plant ⁻¹)			Root dry weight (g plant ⁻¹)			Corm dry weight (g plant ⁻¹)			Corm humidity (%)		
	Soil texture			Soil texture			Soil texture			Soil texture		
	CS	SCL	SS	CS	SCL	SS	CS	SCL	SS	CS	SCL	SS
20% ET _c	12Cb ^a	11Bb	13Ca	9Db	10Cab	11Ca	29Da	32Ba	29Ca	46Ca	41Da	42Ca
60% ET _c	15Ca	13Bb	15Ca	15Ca	16Ca	16BCa	33CDa	37Ba	42Ca	65Ba	60Ca	67Ba
100% ET _c	19BCa	17Ba	20Ba	20Ba	18Ca	20Ba	49BCa	51Aa	58Ba	78Aa	68Bb	68Bb
140% ET _c	26Aa	25Aa	26Aa	25Aa	30Ba	21Ba	68Aa	62Aa	70Ba	76Aa	76Aa	74Aa
180% ET _c	32Aa	24Aa	27Aa	28Aa	38Aa	27Aa	60ABb	58Ab	83Aa	77Aa	78Aa	73Aa

^a Mean separation between water regimes within soil texture (capital letters) and between soil textures within water regime (lower case letters) by t-test at $\alpha = 0.05$.

3.4 DISCUSSION

The chemical composition of taro corm has been well documented (Onwueme, 1978; Bradbury et al., 1985), while little information was recorded about pH, total soluble solids (TSS), and total titratable acidity (TTA) in taro corm, leaf, and petiole. In the current study, pH taro corm, leaf, and petiole were slightly above of 6.0, it can be observed that the taro was in a good state of maturation and conservation since lower pH values are better for the action of enzymes which degrade starch (Nardin, 2009). The values for pH in taro corm in the current study were higher than those reported by Feltran et al. (2004) in potato, while which were similar to those verified on potato by Nardin (2009) and Fernandes et al (2010). In the current study, 20% ET_c (7.0%) and 60% ET_c (7.3%) showed higher TSS in taro corm compared with the other irrigation treatments (Figure 3.4 d). In a study conducted by Robles (2003) who observed the value of TSS ranged from 5.88 to 5.93% in potato. However, according to the research of Pereira (1987), lower TSS is not indicative of poor corm quality. Little variation was observed for TTA with respect to water regime, but higher variations were observed between soil textures for taro corm and petiole. Sandy soil (SS) showed higher TTA in taro corm and petiole, compared with that of CS and SCL (Figure 3.4 g, i). Overall, higher water regime was more suitable for the behavior of this variable, and SS may be more possible to get higher TTA under the same level of

irrigation treatment, which may affect ultimately the flavor of taro.

One of the most important components in taro corm is carbohydrates (Kaur et al. 2011). Starch as the main carbohydrate in taro corm, is also one of the most important sources of carbohydrates in food and is gaining more and more attention because of its health benefits (Bezerra et al., 2013,). In the current study, starch content (SC) ranged between 16% and 20%, TS ranged from 1.7% to 3.1%, PC varied from 1.5% to 3.0%, which are similar to the investigation by Onwueme (1994), whereas higher than those reported on taro by Kaur et al. (2011) and Himeda (2014). According to the results in Table 3.5, worthy of note here is that higher water availability is more beneficial to the accumulation of SC rather than that of PC. As with increase in water regime, the PC reduced, whereas SC was increased in response to the augment of water regime. In addition, SS had a positive effect on SC (Table 3.5). As a good source of carbohydrate for infant weaning diets (Kaushal et al., 2015), the content of carbohydrates and protein influence the quality and flours of taro corm. Experiments conducted to clarify the relationships between the chemical composition and consumers' preferences indicate that taro corm with high dry matter and starch content but with low total sugars are preferred (Lebot et al. 2004, 2011).

It is clear that the ADW, RDW, and CDW per plant were depressed by lower water regimes. Similar results were reported by Mabhaudhi et al., (2013) and Bussell et al., (1998), they reported that taro leaf dry weight and corm dry weight were increased with increase in irrigation level. In the present study, we got a higher CDW in sandy soils (SS). It is well known that SS has a lower ability to hold water which leads to low fertility as its light texture and loose structure. But with organic matter, sandy soil is good for growing many varieties of vegetables and is well suited to tuber crops (Fry, <https://living.thebump.com/properties-sandy-soils-9588.html>). The compost heap was done twice during the experiment with 1.5 L of organic compost per pot (Table 3.3), the application of organic compost may have a positive effect on the dry mass accumulation of taro in SS. Corm humidity (CH) is very high and varies with variety, growth condition, and harvest time. Generally, the moisture of taro corm ranges

between 63 and 85% (Kaushal et al., 2015). Results reported above demonstrated that limited water availability resulted in reduced CH. CS had higher CH compared with SCL and SS, which was also proved indirectly by the fact that SS obtained higher SC and PC.

3.5 CONCLUSION

Results described here confirmed that irrigation treatment and soil texture affected significantly on chemical composition behavior of taro corm. Higher water regime had a positive effect on taro corm humidity, reducing sugars, starch content, root dry weight, and corm dry weight, whereas had a negative effect on total soluble solids, total titratable acidity, and protein content. In addition, sandy soil may be more suitable to cultivate taro, as total soluble solids, total sugars, protein, starch content, and corm dry weight were observed higher in this soil in comparison with the other soil textures. Though the sandy soil also showed higher total titratable acidity content, which is inadequate to the flavor of taro corms, that we can try to increase the water regime to control the total titratable acidity content. Additionally, results of dry biomass of taro proved again that higher water regime and sandy soil were more beneficial to the growth of taro. Briefly, adequate control of water regime may improve the quality of taro corm, and the application of sandy soil to cultivate taro may be a good way to improve its quality under water limited conditions.

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FINAL CONSIDERATIONS

Taro growth, its corm production and corm quality response to irrigation level and soil texture were discussed in the present study. Based on issues related to botany, environmental requirement, and the importance of taro cultivation presented throughout the general review, the canopy size (leaf number and leaf area), water-use efficiency, and corm yield of taro were discussed in the first chapter; the plant height, petiole diameter, fresh biomass, corm diameter, corm number, and harvest index of taro were analyzed in the second chapter; and the analysis of chemical composition and dry biomass of taro response to water regime and soil texture was done in the last chapter.

With the results reported above, it is possible to conclude that, reasonably controlling the amount of irrigation applied and correctly selecting the soil texture should be key objectives for taro production. Doing so would be helpful to improve its water-use efficiency, corm quality, and possibly corm yield. The taro physiological parameters, yield parameters, and chemical composition parameters responded differently to water regime and soil texture. It is evident that higher water regime played a positive effect on growth and yield of taro, despite that water-use efficiency was higher at 20% ET_c , compared with the other irrigation treatments. It is not necessary to applied irrigation level with 180% ET_c , as higher water regime could decrease water-use efficiency and protein content. In addition, 140% ET_c was observed to have the highest corm yield rather than 180% ET_c as reported above. It is considered to select soil texture correctly to guarantee taro yield and its corm quality with less water applied. The response of taro chemical composition parameters to the treatment in the present study was relatively irregular, it was not simply increased or decreased with the increase or decrease in water regime. Additionally, there was no one soil texture was more beneficial to all the chemical compositions parameters of taro corm, whereas the sandy soil was observed to have higher total sugars, starch content, and total soluble solids than the other two soils. Briefly, adequate control of

water regime may improve growth, corm yield, water-use efficiency, and corm quality of taro. The application of sandy soil to cultivate taro may be a good way to improve its quality under limited water availability conditions.

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