UNIVERSIDAD AUTÓNOMA AGRARIA ANTONIO NARRO

SUBDIRECCIÓN DE POSTGRADO

CRECIMIENTO Y DESARROLLO DE ANTURIO (*Anthurium andreanum* Lind.) EN FUNCIÓN DEL BALANCE IÓNICO EN LA SOLUCIÓN NUTRITIVA

Tesis

Que presenta VIVIANA PAOLA SOSA FLORES

como requisito parcial para obtener el Grado de
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Elaborada por VIVIANA PAOLA SOSA FLORES como requisito parcial para obtener el grado de Doctor en Ciencias en Agricultura Protegida con la supervisión y aprobación del Comité de Asesoría

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Mayra Alejandra Sosa Flores

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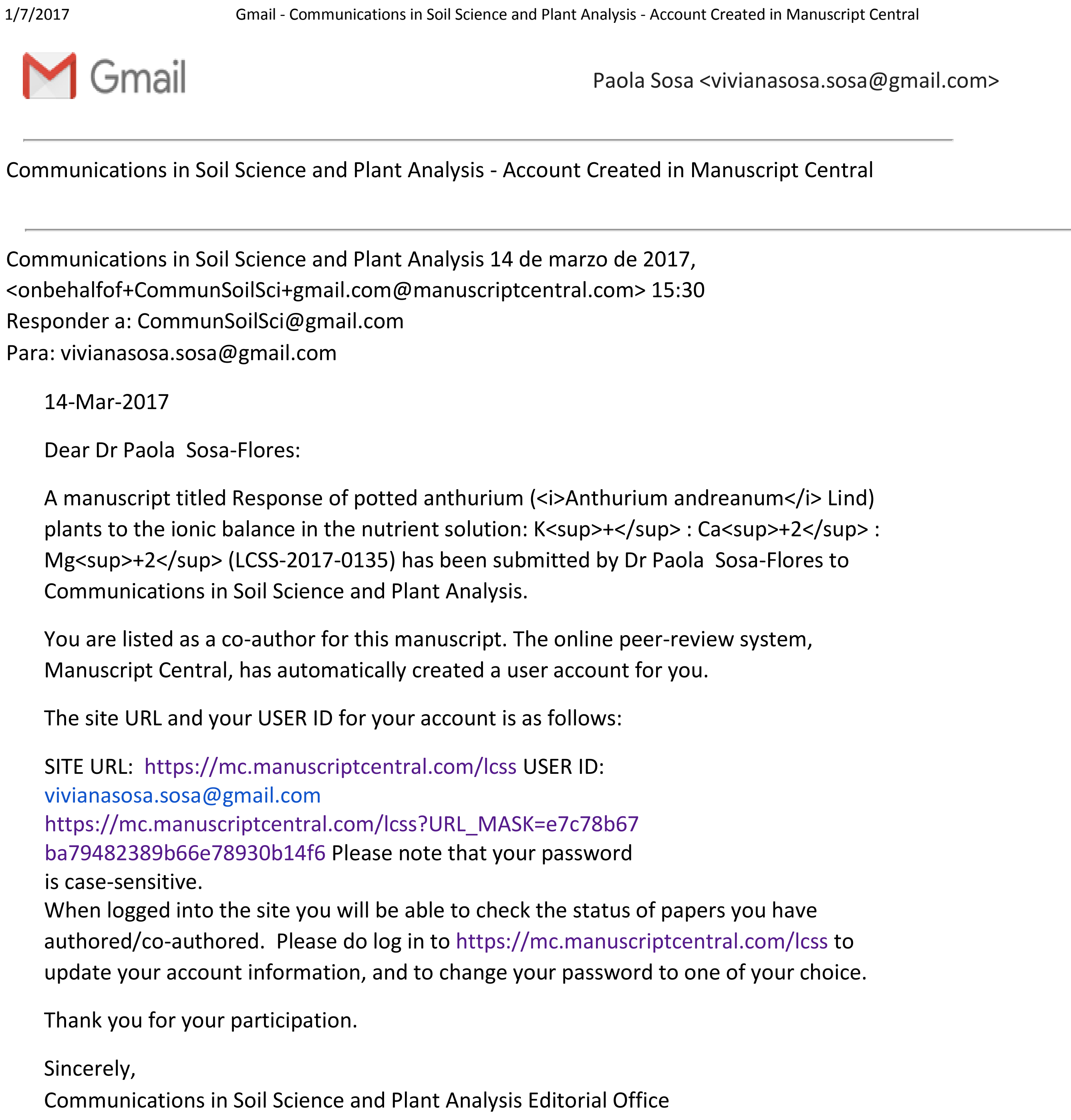

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INTRODUCCIÓN

El anturio (*Anthurium andreanum* Lind.) es una planta epífita sudamericana, valorada por su brillante colorido y por su espata y espádice de larga duración. Pertenece a la familia Araceae y es nativa de las zonas tropicales de Centro y Sur América. El nombre anturio se deriva de la palabra griega '*anthos*' y '*oura*' que significa cola en referencia a su inflorescencia (Mari, 2016). El comercio de anturios en EE.UU se valora alrededor de 50 millones de dólares y entre las flores cortadas tropicales ocupa el segundo lugar en importancia sólo después de las orquídeas. Los Países Bajos y Hawaii son los principales productores y Alemania, Italia, Japón, Francia y Estados Unidos son los principales consumidores (Murguia *et al.*, 2002).

En México, los anturios son cultivados desde hace cincuenta años, principalmente en el estado de Veracruz (Castillo, 2012), principalmente para la producción de flores de corte pero puede adecuarse a cultivos en maceta, es una planta habitualmente grande, de disposición relativamente abierta. La durabilidad de estas flores y su belleza, hacen que tengan un gran potencial para cultivarse en el trópico mexicano (Castillo, 2012) donde existen condiciones climáticas que permiten producir flores tropicales, como el anturio todo el año, sin embargo, la carencia de investigación básica y aplicada en estas especies no permite identificar nuevas técnicas para aumentar la producción y calidad. El manejo adecuado de soluciones nutritivas puede ser una de ellas. La nutrición es uno de los factores culturales importantes que un cultivador de anturio comercial puede controlar. Sin embargo, se sabe relativamente poco acerca de los requerimientos nutrimentales del anturio (Higaki 1984). La fertilización de anturio crecido en cultivo sin suelo en los países tropicales a menudo se realiza empíricamente.

Los métodos utilizados generalmente conducen al cultivador a sobre estimar las necesidades de la planta y aplicar cantidades excesivas de nutrientes (Dufour y Guérin 2005). Por lo tanto, se pierden minerales y dinero, y hay un riesgo de contaminación de las aguas subterráneas y las corrientes de agua. El ajuste del volumen de la solución nutritiva y su composición, es el primer paso para mejorar el rendimiento de la flor, el uso eficiente de los fertilizantes y la reducción de la contaminación. (Dufour y Guérin, 2005). Las soluciones nutritivas que se utilizan para la producción de cultivos constan de seis macronutrimentos esenciales: tres cationes (K^+, Ca^{+2}, Mg^{+2}) y tres aniones (NO_3^-, $H_2PO_4^-$ y SO_4^{-2}), y en algunas soluciones NH_4^+ en pequeñas concentraciones. Steiner en 1968 introdujo el concepto que se basa en la relación mutua que existe entre los aniones NO_3^-, $H_2PO_4^-$ y SO_4^{-2}, y los cationes K^+, Ca^{+2}, Mg^{+2} con los cuales se regula la solución nutritiva. Tal relación no solo consiste en la cantidad absoluta de cada ión presente en la solución, sino en la relación cuantitativa que guardan los iones entre sí, ya que de existir una relación inadecuada entre ellos, puede disminuir el rendimiento (Steiner, 1968). La importancia del balance iónico comienza cuando las plantas absorben los nutrimentos de la solución nutritiva diferencialmente (Benton, 2015). La razón de esta variación se debe a las diferentes necesidades de los cultivos especie y etapa de desarrollo y la diversidad de condiciones ambientales.

El suministro de nutrientes es uno de los factores clave que afectan el crecimiento y rendimiento de flores de anturio (Chang *et al.,* 2010). El uso de soluciones nutritivas es una opción viable que nos permite proporcionar al cultivo los nutrientes necesarios para su óptimo desarrollo, sin embargo existen límites fisiológicos, que son los porcentajes mínimos y máximos en que pueden presentarse los iones en la solución nutritiva, para que la planta pueda absorberlos de acuerdo a su relación mutua específica. Si se rebasa estos límites, la planta pudiese no tener los iones disponibles para absorberlos de acuerdo a sus requerimientos específicos, resultando en una nutrición desbalanceada (Steiner 1984). Además, la relación entre los aniones y cationes es de gran importancia, ya que de no cuidar este aspecto, se pueden generar con relativa facilidad deficiencias de algún ion, por lo que es importante no romper el balance entre ellos.

OBJETIVO GENERAL

Determinar el efecto de la modificación del balance de aniones y cationes en la solución nutritiva en el cultivo de anturio en maceta.

Objetivos específicos

Identificar las soluciones nutritivas que contengan un balance de cationes y aniones adecuado para el crecimiento y producción de flores de calidad de anturio en maceta.

Determinar si el efecto de la aplicación de aniones y cationes resulta adecuado para el desarrollo de la planta y flores de anturio.

Hipótesis

El efecto de la modificación del balance de aniones y cationes en soluciones nutritivas resultará en variaciones en el crecimiento de las plantas y en la calidad de flores de anturio en maceta.

REVISIÓN DE LITERATURA

Solución nutritiva universal

Una solución nutritiva para sistemas hidropónicos es una solución acuosa que contiene principalmente iones inorgánicos añadidos a partir de sales solubles de elementos esenciales para plantas superiores. Algunos compuestos orgánicos tales como quelatos de hierro pueden estar presentes. Las soluciones nutritivas más básicas consideran en su composición sólo nitrógeno (N), fósforo (P), potasio (K^+), calcio (Ca^{+2}), magnesio (Mg^{+2}) y azufre (S) y se complementan con micronutrientes. Una característica importante de las soluciones de nutrientes es que deben contener los iones en solución y en formas químicas que pueden ser absorbidas por las plantas, por lo que en los sistemas hidropónicos la productividad está estrechamente relacionada con la absorción de nutrientes y la regulación del pH (Steiner, 1968). El pH es un parámetro que mide la acidez o alcalinidad de una solución. Este valor indica la relación entre la concentración de iones libres H^+ y OH^- presentes en una solución y oscila entre 0 y 14, el cambio del pH de una solución nutritiva afecta su composición, especiación y biodisponibilidad. El término "especiación" indica la distribución de los elementos entre sus diversas formas químicas y físicas como: iones libres, complejos solubles, quelatos, pares de iones, fases sólidas y gaseosas y diferentes estados de oxidación (Trejo y Gómez, 2012). Los valores de pH adecuados de la solución nutritiva para el desarrollo de los cultivos se encuentran en el rango de 5.5 y 6.5 (Marschner, 1995).

La concentración iónica total de una solución nutritiva determina el crecimiento, el desarrollo y la producción de plantas (Steiner, 1961). La cantidad total de iones de sales disueltas en la solución nutritiva resulta en una fuerza llamada presión osmótica (PO), que es una propiedad coligativa de las soluciones nutritivas y es notoriamente dependiente de la cantidad de solutos disueltos (Landowne, 2006). Una forma indirecta de estimar la presión osmótica de la solución nutritiva es la conductividad eléctrica (CE), un índice de concentración de sal que define la cantidad total de sales en solución. Por lo tanto, la CE de la solución nutritiva es un buen indicador de la cantidad de iones disponibles para las plantas en la zona de raíces (Nemali y Van Iersel, 2004).

La conductividad eléctrica ideal es específica para cada cultivo y depende de las condiciones ambientales (Sonneveld y Voogt, 2009). Sin embargo, los valores de conductividad eléctrica para sistemas hidropónicos oscilan entre 1.5 y 2.5 dS m (Trejo y Gómez, 2012). La conductividad eléctrica más alta obstaculiza la absorción de nutrientes al acrecentar la presión osmótica, mientras que una conductividad eléctrica más baja logra afectar severamente la resistencia y el rendimiento de las plantas (Samarakoon *et al.,* 2006). La reducción en la absorción de agua está fuertemente y linealmente correlacionada con la conductividad eléctrica. La composición nutritiva determina la conductividad eléctrica y el potencial osmótico de la solución (Trejo y Gómez, 2012). .

Balance iónico en soluciones nutritivas.

El balance se refiere a la relación de un elemento con otro y sus formas en la planta, pueden ser tan importantes como la concentración de cualquiera de los elementos en la optimización del estado nutricional de la planta (Steiner, 1980). Existe un equilibrio crítico entre los cationes K^+, Ca^{+2} y Mg^{+2}. Cuando no están en equilibrio, se produce el estrés en la planta. Cuando el K^+ es alto en comparación con Ca^{+2} o Mg^{+2}, el primer efecto probable es la deficiencia de Mg^{+2} (Benton, 2005). En algunos casos, el desequilibrio puede inducir una deficiencia de Ca^{+2}. Un desequilibrio entre estos tres cationes suele ser el resultado de la fertilización excesiva de K^+, ya que K^+ es más fácilmente absorbido y transportado en la planta que el Ca^{+2} o el Mg^{+2} (Benton, 2005). Este antagonismo es mayor entre K^+ y Mg^{+2} que entre K^+ y Ca^{+2}. A pesar de estas diferencias, debe tenerse cuidado de asegurar que el equilibrio adecuado entre K^+, Ca^{+2} y Mg^{+2} se mantenga de manera que no se produzca una deficiencia inducida de cualquiera de estos dos elementos (Steiner, 1980). Por ejemplo, para un mejor crecimiento y producción de fruta para el tomate, el contenido de K^+ y Ca^{+2} en hojas recientemente maduras debería ser aproximadamente el mismo (Benton, 2005).

Steiner (1961) ha sugerido que sólo cierta cantidad de proporciones en la solución de nutritiva son útiles. En el mejor de los casos, sólo una formulación sería suficiente para la mayoría de las plantas mientras se mantenga el equilibrio iónico entre los elementos. La solución nutritiva en que la mayoría de las plantas crecerán extremadamente bien debe contar con el siguiente porcentaje de relaciones equivalentes de aniones y cationes: NO_3^-

, 50 a 70% de aniones; $H_2PO_4^-$, 3 a 20% de aniones; SO_4^{-2}, 25 a 40% de aniones; K^+, 30 a 40% de cationes; Ca^{+2}, 35 a 55% de cationes y Mg^{+2} 15 a 30% de cationes.

La importancia del balance iónico comienza cuando las plantas absorben los nutrimentos de la solución nutritiva diferencialmente (Benton, 1997). La razón de esta variación se debe a las diferentes necesidades de los cultivos (especie y etapa de desarrollo) y la diversidad de condiciones ambientales. La restricción de estos rangos, además de ser de tipo fisiológico, es química, lo cual está determinado principalmente por la solubilidad de los compuestos que se forman entre $H_2PO_4^-$ y Ca^{+2}, y SO_4^{2-} y Ca^{+2}. El límite de solubilidad del producto de los iones fosfato y calcio es de 2.2 mmol L^{-1}, y del producto entre el sulfato y el calcio, de 60 mmol L^{-1} (Steiner, 1984). Las plantas son selectivas al absorber nutrimentos, lo cual significa que, a pesar de que la solución nutritiva tenga una relación determinada entre aniones y/o cationes, las plantas no necesariamente las absorben en esa misma proporción. La relación original entre iones en la solución nutritiva, en circuitos cerrados, se modifica debido a la absorción selectiva de nutrimentos por las plantas: generalmente se incrementan los SO_4^{-2} respecto a los NO_3, y el Ca^{+2} respecto al K^+; sin embargo, la modificación de la solución nutritiva no es siempre en el mismo sentido, ya que depende también de las condiciones ambientales y de la etapa de desarrollo (Favela *et al.*, 2006).

La interacción de los nutrientes está influenciada por factores tales como la concentración, la temperatura, la intensidad de la luz, la aireación , el pH, la arquitectura de la raíz, la tasa de transpiración y respiración de la planta, la edad y la tasa de crecimiento de la planta. La influencia neta de estas interacciones y procesos produce el rendimiento de un cultivo (Fageria, 2001).

El ambiente influye más en la absorción de SO_4^{2-} que en la de $H_2PO_4^-$ y NO_3^-; mientras que la absorción de Ca^{+2} la afecta en mayor medida que la de K^+ y Mg^{+2}, lo cual se debe a los mecanismos de absorción de éstos últimos; el NO_3^-, el $H_2PO_4^-$, el K^+, y en menor proporción el Mg^{+2}, las plantas los absorben en forma activa, lo que significa que invierten energía metabólica. El desbalance entre los iones en la solución nutritiva puede ocasionar antagonismo y/o precipitación entre algunos de ellos. La acumulación de SO_4^{2-} favorece la precipitación de Ca^{+2}. El incremento de la acumulación de Ca^{+2} provoca la pérdida por precipitación de SO_4^{-2} y $H_2PO_4^-$ (Favela *et al.*, 2006).

La restricción del equilibrio iónico es la razón principal de la imposibilidad de añadir un solo elemento a la solución nutritiva o al sustrato en crecimiento sin añadir o agotar otros iones (Kläring, 2001). El reconocimiento de la importancia del balance de nutrientes en la producción de cultivos es una referencia indirecta de la contribución de las interacciones al rendimiento. Los rendimientos más altos se obtienen cuando el nutriente y otros factores de crecimiento están en un estado favorable de equilibrio. A medida que uno se aleja de este estado de equilibrio, los antagonismos de los nutrientes se reflejan, con rendimientos reducidos. Las interacciones antagonistas y sinérgicas están determinadas por el nivel de cada nutriente en la solución nutritiva, por las diferencias entre las especies vegetales e incluso entre los cultivares de la misma especie. Además, las propiedades físicas, químicas y biológicas del suelo o sustrato también cambian los patrones de interacción de los nutrientes en las plantas (Fageria, 2001).

La calidad y la cantidad de fertilizantes aplicados son factores claves que afectan el crecimiento, rendimiento y calidad de la flor de corte de anturio (Dufour y Gueırin, 2005). Sin embargo, el cultivo intensivo de los cultivos normalmente implica una alta tasa de aplicación de nutrientes. La cantidad de fertilizante que se lixivia del suelo afecta la calidad tanto del medio ambiente como de la salud humana (Otero *et al.*, 2005; Schröder y Neeteson, 2008). Mantener la productividad y reducir la aplicación de fertilizantes químicos es cada vez más importante para los cultivadores de flores.

Necesidades nutrimentales de *Anthurium andreanum* Lind.

Se han realizado diversos estudios con el objetivo de determinar las necesidades nutrimentales del cultivo de anturio, por ejemplo al evaluar la influencia de diversas concentraciones de nitrógeno (N) sobre el crecimiento y la absorción de nutrientes de anturio cultivado en fibra de coco bajo diferentes condiciones estacionales. Los tratamientos consistieron en cuatro niveles de concentración de N 79 mg L^{-1}; 105 L^{-1} (control), 158 mg L^{-1} y 210 mg L^{-1} (Chang, 2012). Todos los tratamientos contenían la misma concentración de P, K, Ca, Mg, S, Fe, Cu, Zn, Mo y B. Los resultados muestran que las plantas de anturio tratado con 79 mg L^{-1} de N fueron insuficientes para el crecimiento y rendimiento de anturio. La elevada tasa de aplicación de N (210 mg L^{-1})

también retardó el crecimiento de anturio y el rendimiento de la flor. La concentración de N en el tratamiento de 210 mg L^{-1} fue el más alto, aunque el K^+ y las concentraciones de Mg^{+2} en estas plantas fueron las más bajas entre todos los tratamientos esto puede atribuirse al efecto antagonista entre N y K o entre N y Mg. Las plantas tratadas con 158 mg L^{-1} de N produjeron una flor de corte más comercializable en comparación con las plantas tratadas con 105 mg L^{-1} de N (Chang, 2012).

Higaki et al. (1992), determinaron los niveles óptimos de fertilizante de N, P y K para la producción de flores de anturio en Hawaii. La producción óptima de flores se logró a 312N-448P-375K kg^{-1} ha^{-1} año. Una mayor aplicación de N y K dio lugar a un aumento lineal en el tamaño de la flor. La longitud del tallo de la flor también aumentó con el aumento de las tasas de N, P y K. El rendimiento máximo de la flor se produjo cuando los niveles de tejido foliar fueron de 1.87% de N, 0.17% de P y 2.07% de K. La longitud del tallo y el tamaño de la flor fueron máximos con N de hoja en 1.59% y 1.67% y K en 2.20%, respectivamente. No se observó relación entre el porcentaje de P en hoja, el tamaño de la flor o la longitud del tallo.

Dufour y Guérin (2003), evaluaron el crecimiento, características de desarrollo y producción de flores de *Anthurium andreanum* y para ello utilizaron plántulas cultivadas in vitro del cv 'Cancan' en contenedores de 2.5 L rellenos con un sustrato compuesto de 1: 2 (v: v) de astillas de madera compostadas y grava volcánica de 5-15 mm. La solución nutritiva fue suministrada con un sistema automatizado de riego por goteo. La composición media de la solución fue: macronutrientes (mg L^{-1}): NO_3^-N: 84; NH_4^+-N: 21; P: 46.5; K: 117; Ca: 60; Mg: 28.8. Micronutrients (mg L^{-1}): Zn: 0.2; Mn: 0.5; Cu: 0.06; B: 0.3; Mo: 0.2; Fe: 0.7; pH: 5.8; EC: 1.1 mS cm^{-1}. Se encontró que el desarrollo de *A. andreanum* comienza con una fase vegetativa monopodial seguida por un crecimiento simpodial reproductivo. Además de que en condiciones tropicales, el desarrollo de *A. andreanum* parece ser más regular que en condiciones templadas.

El desarrollo y rendimiento de *Anthurium andreanum* fueron evaluados con la aplicación de la solución nutritiva que contenía 8.9 mmol N y 3.2 mmol K con una relación N-NH_4^+ / N-NO_3^- de 0.37 y dio como resultado un período vegetativo más corto y una producción de flores más grande (Dufour y Guerin, 2003). La solución nutritiva que tuvo la mejor eficiencia en el uso de nutrientes fue N: K: Ca (1: 1: 0.5) en la fase vegetativa y N: K: Ca

(1: 1: 1) en la fase reproductiva. Las plantas del tratamiento N: K: Ca (1: 1: 0.5) aparentemente pudieron almacenar más nutrientes durante la fase vegetativa. A partir de los datos del análisis de la planta del tratamiento N: K: Ca (1: 1: 0.5) (que dio el mejor rendimiento) se proponen dos composiciones diferentes de solución nutritiva, todas en mmol L^{-1} (Dufour y Guerin, 2003):

1.-El primero se debe utilizar durante el período vegetativo cuando la planta crea su raíz y más de una cuarta parte de su área foliar final su composición es: 2.5N-NH; 5.0N-NO_3; 1.0 P; 5.3K; 2.6Ca; 2.1Mg.

2.-Para el período de producción, contiene menos P y K que el primero porque las plantas en la fase reproductiva tienen una tasa menor de P y K: 2.5N- NH_4^+; 5.0 N- NO^-_3; 0.5P; 3.5K; 2.6Ca; 2.1Mg.

Teniendo en cuenta la nutrición de *Anthurium andreanum*, un suministro insuficiente de N y K pueden reducir severamente y retrasar el crecimiento, aumentar la longitud de la fase vegetativa, y reducir el rendimiento. Además, las flores producidas son de peor calidad. (Dufour y Guérin, 2005). Una concentración de 8.9 mmol N L^{-1} de solución nutritiva es suficiente para un buen rendimiento y calidad de la flor. En cuanto a los análisis de minerales, esta concentración podría incluso reducirse a 7.5 mmol L^{-1}. Por otra parte, el suministro de K debe ser alto, especialmente durante la fase reproductiva, cuando hay una exportación intensiva de hojas maduras a flores y hojas jóvenes debido a la gran producción de hojas y flores. Los resultados mostraron que un aumento en la concentración de amonio en la solución nutritiva hasta al menos 1/3 del N total mejora el crecimiento, desarrollo y rendimiento de la planta. Las macetas de 2.5 L rellenas con un substrato que constaba de 5-15 mm de grava volcánica y virutas de madera compostadas y desinfectadas (2:1 v / v) (Dufour y Guérin, 2005).

Kleiber y Komosa en 2006 investigaron la diferenciación del contenido de macroelementos en la solución de nutrientes y en el agua lixiviada sobre el crecimiento de anturio. Las plantas se cultivaron en arcilla expandida con la aplicación de fertirrigación con una solución nutritiva estándar que contenía en mg dm^3: N-NH_4<14.0, N-NO_3 105.0, P 31.0,K 176.0, Ca 60.0, Mg 24.0, S-SO48.0, Fe 0.840, Mn 0.160, Zn 0.200, B 0.220, Cu 0.032, Mo 0.048, pH 5.5–5.7, EC 1.5–1.8 mS·cm. La solución nutritiva se distribuyó por líneas de riego por goteo con emisores situados cada 20 cm. La frecuencia y el tiempo de fertirrigación dependían de la estación del año. En verano, la fertirrigación se aplicó 6-8 veces al día, suministrando 4-5 dm^3 de nutrientes por 1 m. En invierno, el procedimiento se repitió 2-3 veces al día y 2-3 dm se aplicaron.

Posteriormente Kleiber y Komosa en 2010 realizaron la determinación de valores guía para macro y microelementos, el estudio se realizó por tres años en dos granjas comerciales donde usan una solución nutritiva estándar en fertirrigación por goteo. Los valores guía se determinaron en las partes índice de las plantas, que estaban completamente desarrolladas, hojas, después de cortar las flores. Los valores guía incluyen +/- 10% de desviación de la media en el contenido de un nutriente. Se realizaron estudios en 6 cultivares: Barón, Choco, Midori, Pistache, Presidente y Tropical. Los valores medios de 6 cultivares sobre valores guía para *Anthurium cultorum* Birdsey fueron (% en d.m): N 1.40-1.70, P 0.30-0.40, K 3.60-4.50, Ca 1.40-1.80, Mg 0.20-0.30, S 0.30-0.40, y (ppm en d.m) Fe 46.0 – 60.0, Mn 35.0 – 47.0, Zn 54.0 - 72.0, Cu 5.10 – 6.50, B 64.0 - 83.0. También se establecieron valores guía para cv. 'Barón', 'Chocó', 'Midori', Pistache, Presidente y Tropical. La variación varietal se muestra en relación a algunos nutrientes. Cultivares 'Tropical' y 'Choco' se caracterizan por altas gamas de contenido de potasio de 3.80-4.70% y 3.70-4.60% de K, espectacularmente, 'Barón' y 'Presidente' tienen altos rangos de calcio de 1.50-1.90% y 1.50%-2.00% Ca, respectivamente. Cultivar 'Baron' exhibe altos contenidos de hierro que asciende a 52.4-67.0 ppm, 'Choco' manganeso 49.0-64.0 ppm y de cobre 5,60-7,20 ppm, 'Midori' zinc 60.0-80.0 ppm, mientras que 'Pistache' boro 69.0-88.0 ppm. Los valores guía obtenidos permitieron modificar evaluación del estado nutricional de las plantas, así como la optimización del composición de soluciones nutritivas para un determinado cultivar.

En seguida Kleiber y Komosa en 2010, determinaron el contenido de microelementos, (Fe, Mn, Zn, Cu y B) en cultivares de anturio más populares cultivados en Polonia (*Anthurium cultorum* Birdsey) como Baron, Choco, Midori, Pistache, Presidente y Tropical, crecidos en arcilla expandida. Se utilizó fertirrigación por goteo. Se encontró un efecto significativo por el cultivar y la edad de las plantas producidas sobre el contenido de hierro, manganeso, zinc, cobre y boro en hojas de anturio, además que el contenido medio de microelementos en los cultivares analizados fue en el rango para Fe 51.8-54.6, Mn 41.1-1586, Zn 43.2–82.8, Cu 5.35–6.29, B 73.3–73.9 kg^{-1} dm en las partes indicadoras. El contenido más alto de hierro en las partes indicadoras de la planta se encontró en el cultivar Baron; Manganeso y cobre mostraron el mayor valor en cv. Choco. El contenido de zinc fue el más alto en cv. Midori mientras que el contenido de boro fue el más alto en cv. Pistacho. El cobre mostró ser el componente con la menor variabilidad (CV 15.4%-24.3%); el boro fue moderadamente variable (CV 20.9-26.7%); el hierro también se caracterizó por un valor medio de variabilidad (CV 25.1-31.4%), mientras Zinc (CV 39.7-44.7%) y manganeso (cv 40.4-58.5%) mostraron la mayor variabilidad.

Estudios recientes se centran en el efecto de la conductividad eléctrica (EC) en el crecimiento y producción de flores de anturio para ello se utilizaron dos variedades de anturio (Reina Roja y Elizabeth) en condiciones de invernadero utilizando peat moss como sustrato y dos tipos de agua, el primero tipo fue agua destilada y agua de grifo a la que se agregaron algunas sales de fertilizante compuesto por N:P:K con 1:0.5:1.5 para crear diferentes niveles de conductividad eléctrica (0-1 – 1.5-2 ds m^{-1}). Los resultados mostraron que cuando la CE se incrementó por encima de 1 ds m^{-1}, el crecimiento de la planta disminuyó incluyendo el número de flores y hojas. La conductividad eléctrica tiene un efecto sobre la productividad de anturio. Esto era cierto en los dos cultivares estudiados. Se observó que cuando el nivel de conductividad eléctrica se extendió hasta 1 ds m^{-1}, aumentó el número de flores (número de racimos de flores), hojas y diámetro de los grupos de flores. Sin embargo, disminuyeron cuando los niveles de conductividad eléctrica aumentaron más de 1 ds m^{-1}. Los resultados también mostraron que la productividad de los dos cultivares fue mejor cuando se utilizó agua del grifo que el agua destilada y se registraron los valores más altos de los parámetros anteriores en EC = 1 ds m-1en el cultivar Elisabeth en número de racimos de flores y diámetro de racimos de flores (Mohammad *et al.,* 2016).

ARTÍCULO I

Response of potted anthurium (Anthurium andreanum Lind) plants to the ionic balance in the nutrient solution: $K^+ : Ca^{+2} : Mg^{+2}$

Response of potted anthurium (*Anthurium andreanum* Lind) plants to the ionic balance in the nutrient solution: $K^+ : Ca^{+2} : Mg^{+2}$

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Abstract

The climatic conditions of the humid tropical areas of México allow the year-round production of cut flowers and potted plants of anthurium. However, there is scarce basic and applied research on tropical ornamental species, limiting the development of technology to increase their productivity and quality. The present study was designed to determine the effect of varying proportions of cations (K^+, Ca^{+2}, Mg^{+2}) and anions (NO_3^-, $H_2PO_4^-$ and SO_4^{-2}) on the growth and nutrient status of potted anthurium plants. In this paper we are reporting the information as to the effect of the proportions of K^+, Ca^{+2}, Mg^{+2} in the nutrient solution on plant growth responses Using mixture analysis and response surface methodology. Response surface analysis detected that spathe and leaf areas decreased when fed with solutions of high proportions of Mg^{+2}. Total shoot and root fresh weight, as well as total dry weight and root volume, also demonstrated the deleterious effects of high Mg^{+2} ratios. In general, considering all the parameters measured, the best growth of anthurium plants was obtained in two areas of the explored space; one area was high in Ca^{+2}, with optimum ranges from 0.24 – 0.44 for K^+, 0.54 – 0.68 for Ca^{+2}, and 0.01 – 0.08 for Mg^{+2}, and another area that was high in K^+, on which the optimum ranges were 0.54 – 0.65 for K^+, 0.25 – 0.29 for Ca^{+2}, and 0.10 – 0.21 for Mg^{+2}. Shoot and root K^+, Ca^{+2} and Mg^{+2} concentration was significantly affected by the cation ratios, however, there was not a clear tendency as to the effect of each cation in the mixture; nonetheless, the internal $K^+ : Ca^{+2} : Mg^{+2}$ ratios were affected by the external ratios, as in the shoot they were located in a very specific area, indicating that anthurium plants accumulated more Mg^{+2} compared to what it is in the external solution, whereas Ca^{+2} ratio was lower than that of the external solution. As for K^+, plants accumulated it at high rates regardless of the external balance. In conclusion, the optimum nutrient solutions for anthurium may contain very wide ratios of K^+ as long Ca^{+2} and Mg^{+2} are maintained at low proportions.

Keywords: Universal nutrient solution, mineral plant nutrition, ornamental plants, cation balance.

Introduction

Anthurium is one of the most important potted plants cultivated worldwide, however, compared to other tropical ornamental species, the cultivation of anthurium is still limited. The climatic conditions of the humid tropical areas of México allow the year-round cultivation of both, cut flowers and potted anthurium plants. However, there is scarce basic and applied research on tropical ornamental species limiting the development of technology to increase their productivity and quality (Hernández, 2005). High productivity and quality are markedly affected by the nutrient status of ornamental plants; Dudour and Guerín (2005) stated that the knowledge of nutrient requirements by anthurium is an essential factor as growers usually overestimate plant demands, which in turn leads to excessive application of fertilizers, low nutrient use efficiency, environmental pollution and decreased profitability.

According to the principles of the universal nutrient solution by Steiner (1968), the total concentration as well as the ionic balance is of outmost importance in delineating an optimal nutritional program of soilless cultivated plants. The mutual relations of cations (potassium [K^+,], calcium [Ca^{+2}] and magnesium [Mg^{+2}]) is a key factor for plant growth as an unbalanced combination may conduct to a decrease in biomass and yield due to antagonistic relationships among these cations, as reported by Jakobsen (1993) and Ding et al. (2006).

Anthurium is a species that demands a complete fertilization program even though it does not tolerate high concentrations of salts. Özçelik, and Özkan (2000) reported that anthurium is sensitive to an electrical conductivity (EC) higher than 1.0 to 1.5 dS m^{-1}, whereas Sonneveld and Voogt (1983, 1992) reported that it is very sensitive to salinity, with a 22% decrease in growth in response to high EC. Nonetheless, no studies have been performed to elucidate in anthurium the effect of the cation and anion balance in the nutrient solution, which it should be specially considered in potted anthurium as it is cultivated in a soilless medium.

The importance of the ionic balance is due to the facts that 1) plants differentially uptake the nutrients diluted in the medium or nutrient solution (Benton, 2005), 2) the specific needs depend on the developmental stage and environmental conditions on which each plant species is growing. The present study was designed to determine the effect of varying proportions of cations (K^+, Ca^{+2}, Mg^{+2}) and anions (NO_3^-, $H_2PO_4^-$ and SO_4^{-2}) on the growth and nutrient status of potted anthurium plants. In this paper we are reporting the information as to the effect of the proportions of K^+, Ca^{+2}, Mg^{+2} in the nutrient solution.

Materials y methods

Cultural conditions and plant material. The experiment was conducted in a greenhouse with temperature and relative humidity control located at the Universidad Autónoma Agraria Antonio Narro, in Saltillo, Coah., México (25° 21’ 24.37” North Latitude, 101° 02’ 05.45” West Longitude, 1762 m above sea level). Environmental conditions throughout the study were monitored with a data logger (Watch Dog 1000 Series, Spectrum Tecnologies, Inc. Aurora, Illinois). Average temperature was 20 °C (maximum 31.5 °C, minimum 13.5 °C) and average relative humidity was 66% ± 20%. A black screen was installed on the roof of the experimental site to provide a 50% shade, which render an average photosynthetically active radiation of 177 μmol m^2 s^{-1}.

The growing medium consisted of a 1:1 mixture of sphagnum peat (PREMIER, Premier Tech, Home and Garden. Toronto, Canada) (pH = 4.0-4.3, C.E = 0.25 dS m^{-1}) and horticultural-grade perlite (33% water capacity retention, 64% pore space with air, 0.25 $g \cdot cm^{-3}$ apparent density). The mixture was adjusted to a pH of 6.3 using sodium bicarbonate prior placement in 15.2 cm pots. Anthurium (cv. Tropical) 12-15 cm plants with 2-3 young leaves were used for this study. Transplant was performed on 17 Oct. 2014 and harvest on 20 Oct. 2015.

Nutrient solutions. The treatments consisted of 10 nutrient solutions whose total sum of anions and cations was 20 meq L^{-1} each. The nutrient solutions were randomly selected using Design Expert v. 9.0 (Company Stat Ease, Inc. Minneapolis, Minnesota) (Table 1). The pH of the nutrient solutions was held from 5.5 to 6.0 and EC was 2.0 dS m^{-1}. The limits for K^+ proportion in the nutrient solutions ranged from 0.08 to 0.65, whereas for Ca^{+2} and Mg^{+2} were 0.25 to 0.68 and 0.01 to 0.33, respectively (Fig. 1). As a control treatment, we included a nutrient solution with Steiner´s formulation (Steiner, 1973) containing (in meq L^{-1}): 12 NO_3^-, 1 $H_2PO_4^-$, 7 SO_4^{-2}, 9 de Ca^{+2}, 7 K^+, and 4 Mg^{+2}. Micronutrients in all the nutrient solutions were provided at the following concentrations: 4 ppm Fe-EDTA, 2 ppm Mn-EDTA, 0.37 ppm B, 0.32 ppm Zn-EDTA, 0.16 ppm Cu-EDTA, and 0.11 ppm Mo. Plants were manually irrigated when needed maintaining a leaching fraction of 30%.

Assessment of plant growth and nutrient status. At harvest, plants were separated into root and shoot and washed with deionized water. Leaf and spathe areas were measured with an Area Meter (Model LI-3100C, LI-COR Inc. Nebraska, USA). The length of the flowering stem from all the flowers was also measured. Root volume was determined by measuring water displacement in a graduated cylinder. After harvest, fresh shoot and root weight was measured in all the plants. To determine the dry weight, shoots and roots were placed in an oven at 70°C until constant weight was obtained. Dry tissues were weighed and then digested in a 2:1 mixture of H_2SO_4:$HClO_4$ plus 2 ml of 30 % H_2O_2 prior mineral analysis. Mineral analysis included K^+, Ca^{+2} and Mg^{+2} using inductively coupled plasma emission spectrometer (ICP-AES, model Liberty; VARIAN, Santa Clara, CA).

Statiscal design and analysis. The 10 plus the control nutrient solutions with four 1-pot replications were distributed in a randomized complete block design. Data were analyzed with SAS v 9.0 to conduct an analysis of variance; when significance was detected, a multiple comparison test was performed with Duncan´s procedure ($p < 0.05$). In addition, the effect of the K^+, Ca^{+2} and Mg^{+2} ratios in the nutrient solutions on plant growth responses was modeled using mixture analysis and response surface methodology with Desing Expert® v 9.0. The models selected were those with the highest R^2 and p-value, along with an adequate precision higher than 4.0 and a non-significant lack of fit, which indicates that the model can be used to predict the response of plants when used within the space on which it was designed. A regression analysis was conducted when a significant response of plant growth and nutrient concentration in plant tissues was detected.

Results and discussion

Several nutrient solutions of different $K^+ : Ca^{+2} : Mg^{+2}$ ratios resulted in growth promotion of anthurium plants. Compared to the control, certain cation ratios allowed the increase of spathe and leaf area, root volume, root and shoot fresh and dry weight (Table 2). Response surface analysis allowed the identification of nine growth parameters whose models can be used to explore the space area designed for the present study (Table 3); leaf and spathe areas and root volume were decreased with high proportions of Mg^{+2}, in contrast, low Mg^{+2} ratios combined with high ratios of Ca^{+2} or K^+ resulted in plants with larger leaf and spathe area (Fig. 2).

Similar to spathe and leaf area and root volume (Fig. 2), total, shoot and root fresh weight (Fig. 3) demonstrated the deleterious effects of high Mg^{+2} ratios in the nutrient solutions as plants fed with solutions of low Mg^{+2} ratios combined with high ratios of Ca^{+2} or K^{+} resulted with increased biomass and root volume. The detrimental effect of high ratios of Mg^{+2} was also observed in the total, shoot and root dry weight (Fig. 4), although Ca^{+2} and K^{+} caused contrasting responses as high ratios of Ca^{+2} promoted shoot dry weight whereas high K^{+} ratios enhanced root dry weight (Fig. 6).

In general, considering all the parameters measured, the best growth of anthurium plants was obtained in two areas of the explored space; one area was high in Ca^{+2}, with optimum ranges from 0.24 – 0.44 for K^{+}, 0.54 – 0.68 for Ca^{+2}, and 0.01 – 0.08 for Mg^{+2}. The other area was high in K^{+}, on which the optimum ranges were 0.54 – 0.65 for K^{+}, 0.25 – 0.29 for Ca^{+2}, and 0.10 – 0.21 for Mg^{+2}. The best growth under high K^{+} or Ca^{+2} proportions is probably due to an optimum balance of the cations, which allowed an adequate supply of those nutrients. The results of the present study suggest that excess Mg^{+2} in the nutrient solution resulted detrimental for the growth of potted anthurium plants. Dofour and Guérin (2005) indicated that an adequate supplement of K^{+} increased the growth and flower production of anthurium plants, while reducing the length of the vegetative phase. Anthurium is highly demanding of K^{+} as, according to Kleiber et al. (2009), optimum K^{+} concentrations in plant tissues range from 3.41% to 3.98% for the autumn – winter season and from 4.01% to 4.32% for the spring – summer season. Calcium nutrition is also very important for anthurium as the flowers are very sensitive to Ca^{+2} deficiency, causing a color breakdown in the spathe (Higaki, Rasmussen and Carpenter 1980).

Shoot and root K^{+}, Ca^{+2} and Mg^{+2} concentration was significantly affected by the cation ratios (Table 4), however, there was not a clear tendency as to the effect of each cation in the mixture, resulting in non-significant models (models not shown). Nonetheless, the internal K^{+} : Ca^{+2} : Mg^{+2} ratios were affected by the external cation ratios. Except for the plants fed with the 0.22 : 0.57 : 0.21 ratio, all the internal ratios in the shoot were located in a very specific area (Fig. 5), indicating that anthurium plants regulate the accumulation of cations according to its demands. Steiner (1973) reported similar trends in tomato (*Solanum lycopersicum* L.) plants, concluding that this species have a strong selective capacity for cations and anions uptake in a given ratio, regardless of the ratio in the nutrient solution. The location of the area for the internal cation ratio suggests that anthurium plants were highly selective for Mg^{+2} uptake as the internal ration was higher than that of the external solution (Fig. 5). Anthurium plants showed a high selectivity for K^+ uptake as it was accumulated at high rates regardless of the external balance (Fig. 5). In contrast, anthurium was selective for Ca^{+2} exclusion as suggested by the lower internal ratio compared to that of the external solution (Fig. 5).

In the roots, anthurium plants also exhibited a high selectivity to exclude the uptake of Mg^{+2} and Ca^{+2}, however, in contrast to the shoot, there was a broad K^+ internal ratio, which was similar to that of the external solutions (Fig. 5). This differential response in the roots may be due to the accumulation of the nutrient solution in the empty lumen of the non-living velamen cells, a tissue specialized in water conservation in epiphytic species (Higaki, Rasmussen and Carpenter, 1984).

The antagonism between K^+, Ca^{+2} and Mg^{+2} has been well documented (Jakobsen, 1993; Ding, Luo and Xu 2006). Similarly, in anthurium, Chang et al. (2010) reported results indicating that, at a whole plant level, increasing K^+ was associated with a decrease in Ca^{+2}, while increasing Ca^{+2} reduced that of Mg^{+2}, confirming the antagonism between these cations. However, the authors also presented results that did not suggest an antagonistic relation between K^+ and Mg^{+2} as the concentration of both tended to increase (Chang et al., 2010). Similar results were reported by Kleiber et al. (2009) in a study performed during the autumn – winter for three consecutive years in anthurium cv Tropical, as increasing Ca^{+2} concentration in plant tissues was associated with an increase in Mg^{+2}. In the present study, comparable tendencies were observed as the concentration of Ca^{+2} and Mg^{+2} in the shoot increased (Fig. 6), however, this was observed only at low concentrations of both cations, suggesting that this response was due to the concentrations used in our study. In fact, the synergistic or antagonistic relation between two cations may be concentration-dependent, as reported by Narwal, Kumar and Singh (1985) for K^+ and Mg^{+2} in cowpea (*Vigna unguiculata* (L.) Walp.).

The importance of the Ca^{+2} and Mg^{+2} balance in anthurium is more evident when considering that increasing root Ca^{+2} concentration was correlated with a decrease in leaf area, root volume and shoot and root dry weight (Fig. 7), whereas increasing shoot Ca^{+2} and Mg^{+2} concentration was associated with a decrease in root and shoot dry weight, respectively (Fig. 8).

Calculating the concentration of K^+, Ca^{+2} and Mg^{+2} from the optimum ratios, the nutrient solutions for anthurium must contain 4.8 – 8.8 meq L^{-1} K^+, 10.8 – 13.6 meq L^{-1} Ca^{+2}, and 0.02 – 0.16 meq L^{-1} Mg^{+2}, and the other area high in K^+ they must contain 10.8 – 13.0 meq L^{-1} K^+, 5.0 – 5.8 meq L^{-1} Ca^{+2}, and 2.0 – 2.2 meq L^{-1} Mg^{+2}. Dofour (2001) indicated that the best growth of anthurium plants is achieved when fed with solutions containing 2.25 meq L^{-1} of Ca, while Chen, Zhang and Liang (2010) reported a Mg optimum concentration of 1.0 meq L^{-1} to obtain maximum growth of anthurium plant and flowers; these Ca^{+2} and Mg^{+2} concentrations are very close to the ones predicted in the present study.

Conclusions

The best nutrient solutions for anthurium may contain very wide ratios of K^+ as long as Ca^{+2} and Mg^{+2} are maintained at low proportions. Regardless of the $K^+ : Ca^{+2} : Mg^{+2}$ ratios in the nutrient solution, anthurium plants regulated the accumulation of these cations, achieving similar ratios in the shoot tissues, so that, even though Ca^{+2} ratio may be high and Mg^{+2} may be low in the nutrient solutions, the plants tended to accumulate less Ca^{+2} but more Mg^{+2}. Excess accumulation of Ca^{+2} and Mg^{+2} resulted in decreased growth.

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Table 1. Proportion of anions and cations in the nutrient solutions assessed.

Nutrient Solution	NO_3^-	$H_2PO_4^-$	SO_4^{-2}	K^+	Ca^{+2}	Mg^{+2}
1	0.43	0.05	0.52	0.42	0.25	0.33
2	0.80	0.02	0.18	0.48	0.51	0.01
3	0.78	0.12	0.10	0.08	0.59	0.33
4	0.63	0.05	0.33	0.31	0.68	0.01
5	0.78	0.12	0.10	0.51	0.36	0.14
6	0.20	0.12	0.68	0.65	0.25	0.10
7	0.49	0.12	0.39	0.09	0.68	0.23
8	0.28	0.02	0.70	0.37	0.47	0.17
9	0.49	0.12	0.39	0.65	0.34	0.01
10	0.36	0.10	0.55	0.22	0.57	0.21
Control	0.60	0.05	0.35	0.35	0.45	0.20

Table 2. Effect of the K^+ : Ca^{+2} : Mg^{+2} balance in the nutrient solution on growth parameters of anthurium (*Anthurium andreanum* Lind.) plants in response to the K^+ : Ca^{+2} : Mg^{+2} balance in the nutrient solution

K^+	Ca^{+2}	Mg^{+2}	Spathe area (cm^2)	Leaf area (cm^2)	Root volume (cm^3)		Shoot	Root	Total		Shoot	Root	Total
Proportion							fresh weight (g)				dry weight (g)		
0.42	0.25	0.33	118a	534bcd	52.0d		52.6cd	55.0b	108cde		5.86cd	7.26bc	13.6bcd
0.48	0.51	0.01	149a	758abc	117.0ab		88.3a	86.9ab	177abc		11.60ab	8.96abc	22.0a
0.08	0.59	0.33	133a	791ab	65.0cd		78.7ab	104.0ab	183ab		10.20abc	9.11abc	20.5ab
0.31	0.68	0.01	131a	1020a	143.0a		103.0a	125.0a	228a		13.10a	11.30ab	23.7a
0.51	0.36	0.14	150a	824ab	103.0bc		77.0ab	97.0ab	174abcd		9.68abc	10.10abc	19.2abc
0.65	0.25	0.10	169a	790ab	151.0a		85.7a	122.0a	208ab		9.94abc	12.70a	21.5a
0.09	0.68	0.23	153a	642bcd	100.0bc		74.3ab	77.4ab	152bcde		7.93bcd	8.52abc	17.9abcd
0.37	0.47	0.17	149a	430d	52.0d		36.9c	43.8b	81e		8.33abcd	5.49c	11.5d
0.65	0.34	0.01	54b	483cd	50.0d		46.9bc	59.0b	106cde		5.57cd	6.58c	12.9cd
0.22	0.57	0.21	62b	410d	42.5d		47.7cd	49.1b	97e		5.56cd	6.17c	10.9d
0.35	0.45	0.20	42b	412d	44.4d		28.4c	73.1b	101de		4.35d	6.89c	11.9d

Table 3. Models that estimate the spathe and leaf area, root volume and shoot, root, and total fresh (FW) and dry weight (DW) of anthurium (*Anthurium andreanum* Lind.) plants to the $K^{+} : Ca^{+2} : Mg^{+2}$ balance in the nutrient solution.

Growth parameter	Model	P <	R^2
Leaf area (cm^2)	$= -201K + 1615Ca + 4119Mg + 55.2KCa - 1060KMg - 5658CaMg - 23892KCaMg + 21726KMg(K-Mg)$	0.01	0.72
Spathe area (cm^2)	$= -14.7K - 3.93Ca + 2685Mg + 70.6KCa - 4595KMg - 4857CaMg + 4357KCaMg + 2299KMg(K-Mg) + 2767CaMg(Ca-Mg)$	0.01	0.80
Root volume (cm^3)	$= 5.88K + 373Ca + 1376Mg - 427KCa - 2368KMg - 2432CaMg + 5767KMg(K-Mg)$	0.01	0.64
Shoot FW (g)	$= 43.1K + 233Ca + 991Mg - 304KCa - 1578KMg - 1671CaMg + 2839KMg(K-Mg)$	0.01	0.60
Root FW (g)	$= 33.1K + 299Ca - 4016Mg - 296KCa + 7488KMg + 7481CaMg - 10435KCaMg - 5066CaMg(Ca-Mg)$	0.03	0.51
Total FW (g)	$= -7.35K + 450Ca + 1644Mg - 261KCa - 2029KMg - 2649CaMg - 2703KCaMg + 6322KMg(K-Mg)$	0.01	0.68
Shoot DW (g)	$= -5.82K + 22.6Ca + 138Mg + 0.32KCa - 229KMg - 211CaMg + 45.1KCaMg + 382KMg(K-Mg)$	0.01	0.41

Root DW (g)	$= 4.06K + 22.9Ca - 294Mg - 17.7KCa + 582KMg + 538CaMg - 831KCaMg - 316CaMg(Ca-Mg)$	0.01	0.60
Total DW (g)	$= - 15.9K + 29.5Ca + 114Mg + 50.7KCa - 68.4KMg - 129CaMg - 522KCaMg + 590KMg(K-Mg)$	0.01	0.62

To estimate a growth parameter, do select the respective model, then substitute the proportion of each cation in the mixture of interest and multiply it by the corresponding coefficient. For example, to estimate leaf area of plants irrigated with a solution with a cation balance of 0.42 K^+, 0.25 Ca^{+2}, 0.33 Mg^{+2}, the model would be = -201*(0.42)+1615*(0.25)+4119*(0.33)+55.2*(0.42*0.25)-1060*(0.42*0.33)-5658*(0.25*0.33)-23892*(0.42*0.25*0.33)+21726*(0.42*0.33)*(0.42-0.33)

Table 4. Effect of the K^+: Ca^{+2}: Mg^{+2} balance in the nutrient solutions on the concentration of K^+, Ca^{+2} and Mg^{+2} in shoots and roots of anthurium (*Anthurium andreanum* Lind.) plants.

Nutrient solution			Shoot			Root		
K^+	Ca^{+2}	Mg^{+2}	K^+	Ca^{+2}	Mg^{+2}	K^+	Ca^{+2}	Mg^{+2}
Proportion			mmol kg^{-1}					
0.42	0.25	0.33	229abc	247a	259ab	264b	369abc	550cdef
0.48	0.51	0.01	223abc	241ab	234bc	103e	272cd	410f
0.08	0.59	0.33	266ab	234ab	249ab	145de	330bcd	736a
0.31	0.68	0.01	197bc	136d	206cd	236bc	217d	429ef
0.51	0.36	0.14	245abc	178bcd	239bc	230bc	228d	248g
0.65	0.25	0.10	289a	148d	248abc	366a	224d	436ef
0.09	0.68	0.23	219abc	223abc	285a	149de	480a	713ab
0.37	0.47	0.17	177c	217abc	242abc	149cde	382abc	684abc
0.65	0.34	0.01	276a	244ab	272ab	148de	368abc	499bc
0.22	0.57	0.21	267d	192abcd	238bc	134de	452ab	625abcd
0.35	0.45	0.20	239abc	161cd	235bc	181cd	460abc	576bcde

Means followed by the same letter indicates no significant difference according to Duncan´s comparison test ($P < 0,05$).

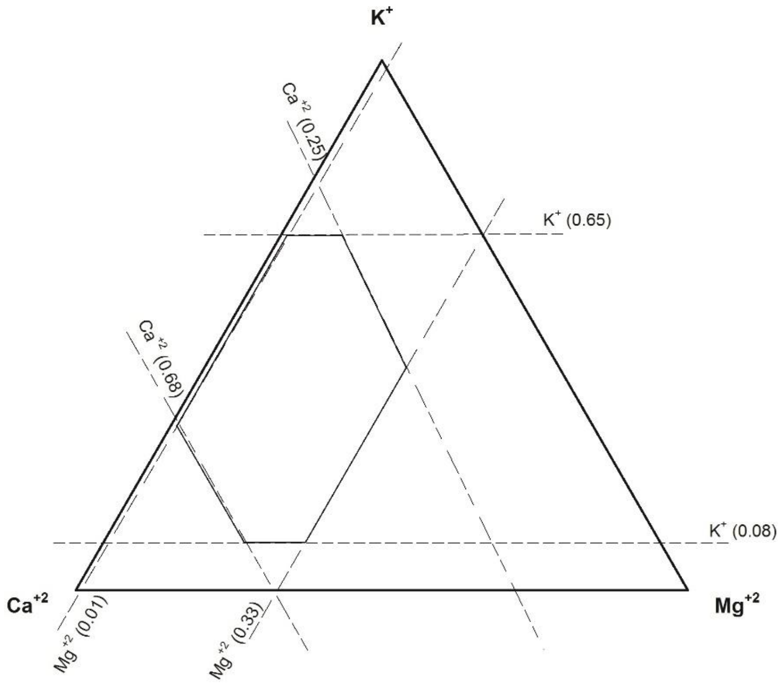

Figure 1. Desing points corresponding to the mixtures of K$^+$, Ca^{+2} and Mg^{+2} in the nutrient solutions. The lines demarcate the minimum and maximum proportion of each cation.

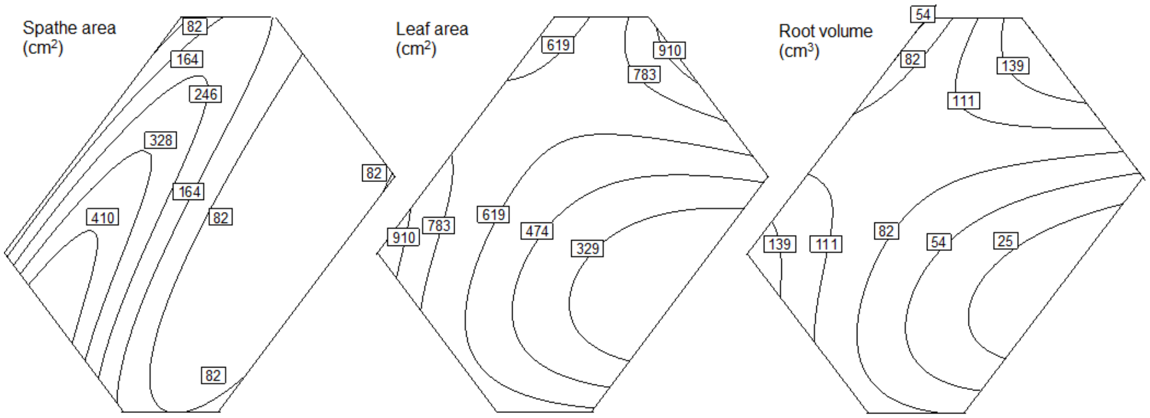

Figure 2. Counter plots showing the effect of the K$^+$: Ca^{+2} : Mg^{+2} balance in the nutrient solution on leaf area (cm^2), spathe area (cm^2) and root volume (cm^3) in anthurium (*Anthurium andreanum* Lind) plants.

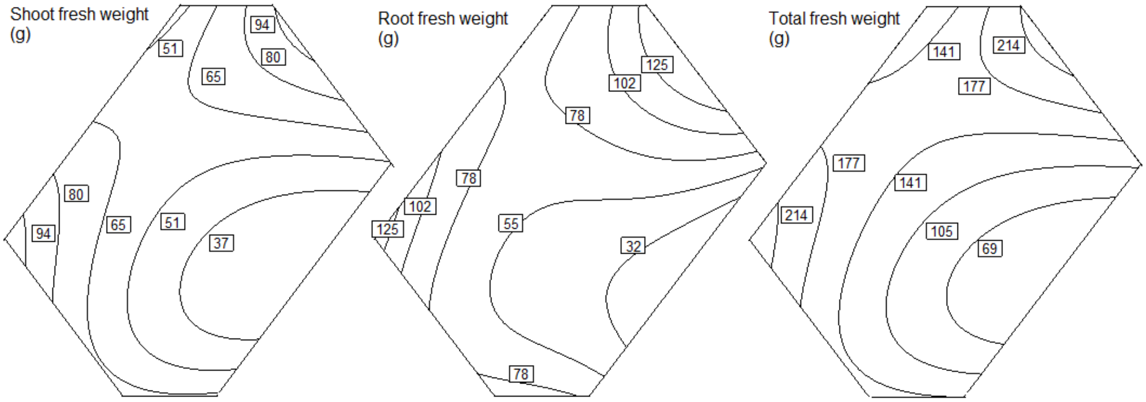

Figure 3. Counter plots showing the effect of the $K^+ : Ca^{+2} : Mg^{+2}$ balance in the nutrient solution on shoot fresh weight, root fresh weight and total fresh weight in anthurium (*Anthurium andreanum* Lind) plants.

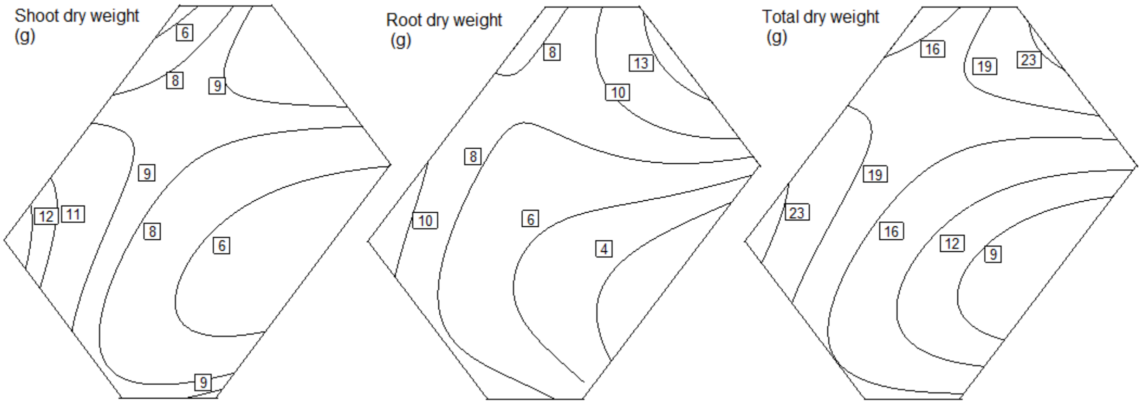

Figure 4. Counter plots showing the effect of the $K^+ : Ca^{+2} : Mg^{+2}$ balance in the nutrient solution on shoot dry weight, root dry weight and total dry weight in anthurium (*Anthurium andreanum* Lind) plants.

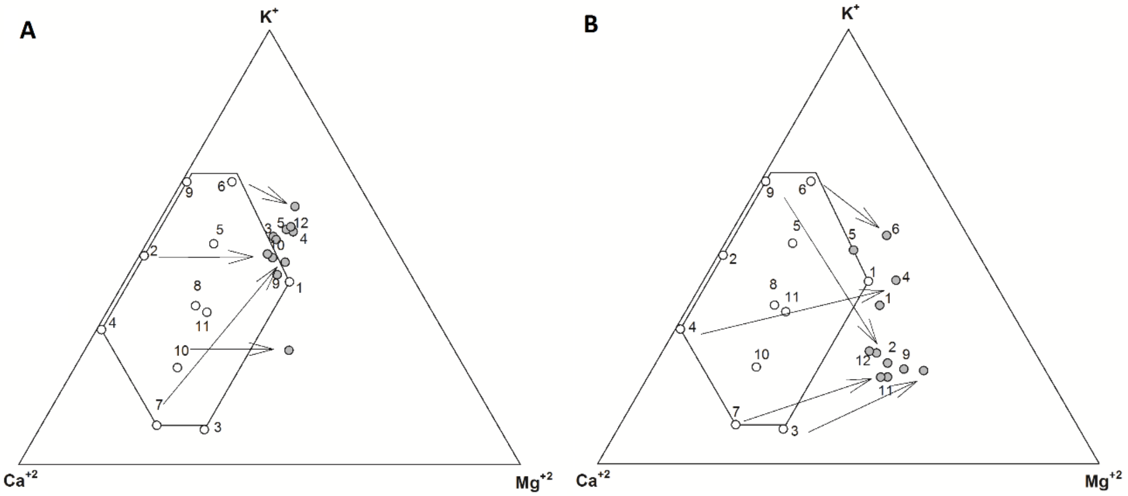

Figure 5. Relationship between the $K^+ : Ca^{+2} : Mg^{+2}$ balance in the nutrient solution (while circles) with the $K^+ : Ca^{+2} : Mg^{+2}$ balance in the shoot (A) and root (B) (grey circles) tissues of anthurium (*Anthurium andreanum* Lind) plants.

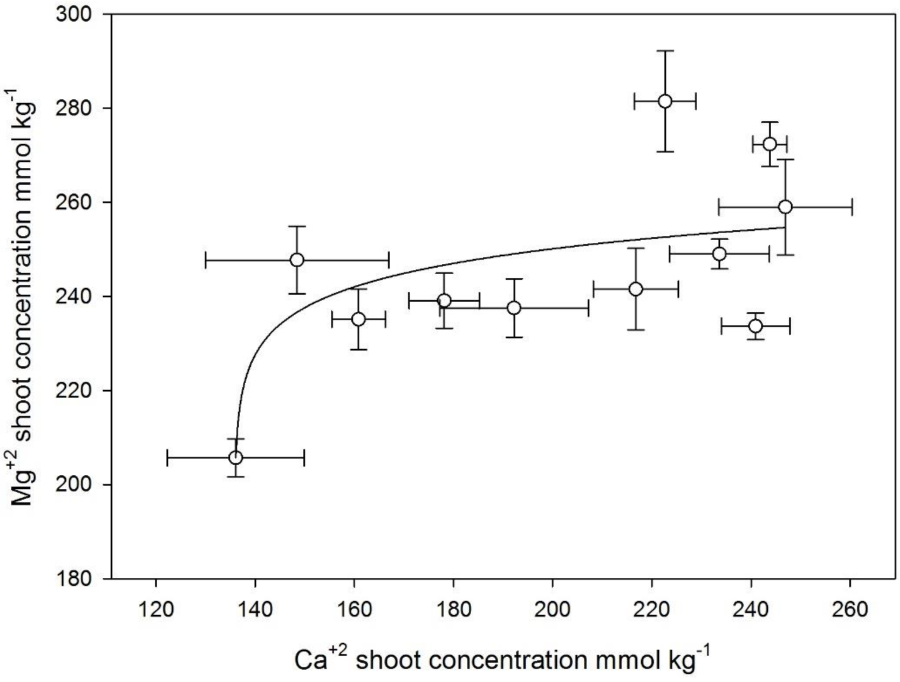

Figure 6. Relationship between the concentration of Ca^{+2} and Mg^{+2} in shoots of anthurium (*Anthurium andreanum* Lind) plants.

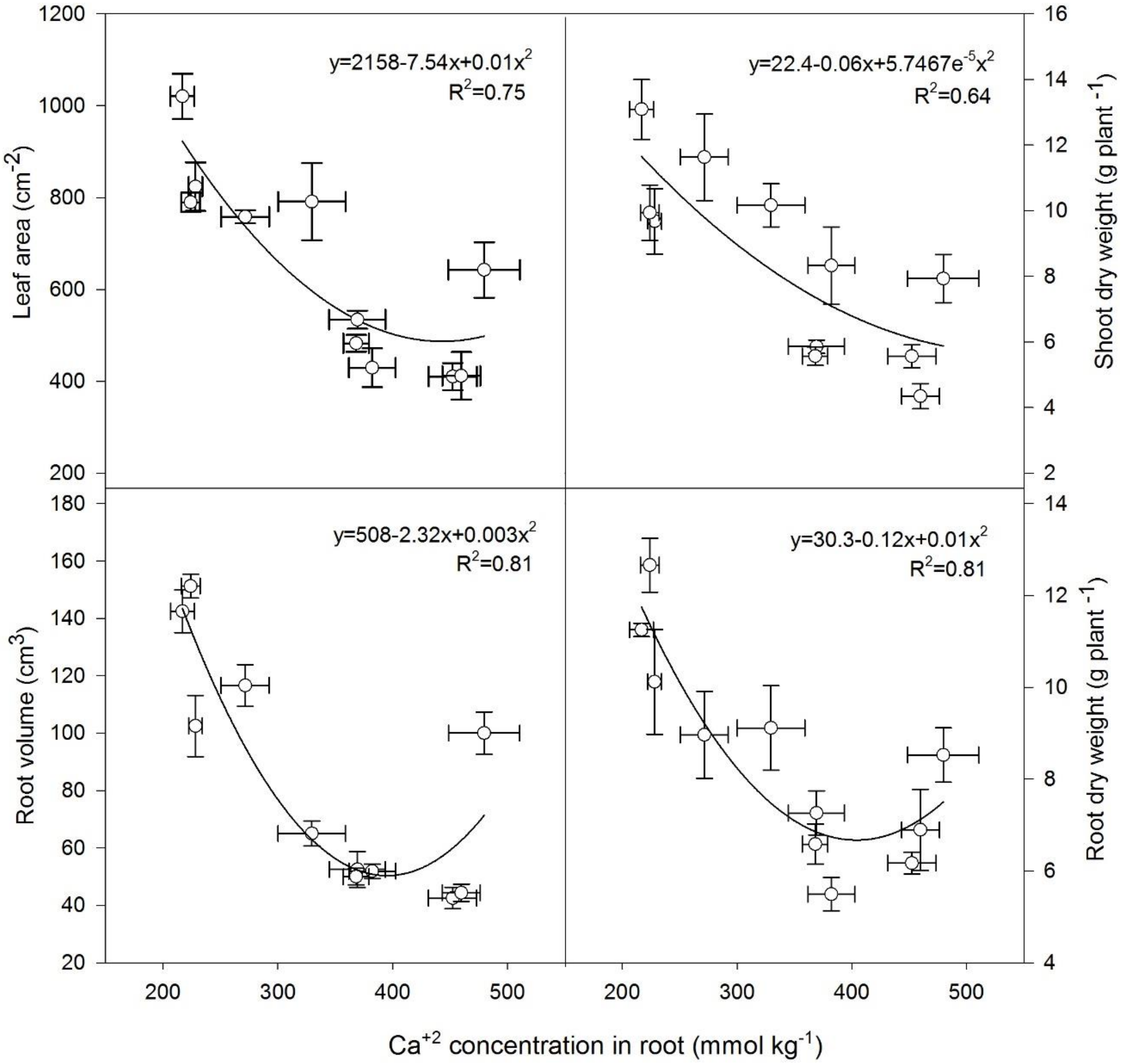

Figure 7. Correlation between root calcium (Ca^{+2}) concentration and growth parameters in anthurium (*Anthurium andreanum* Lind) plants.

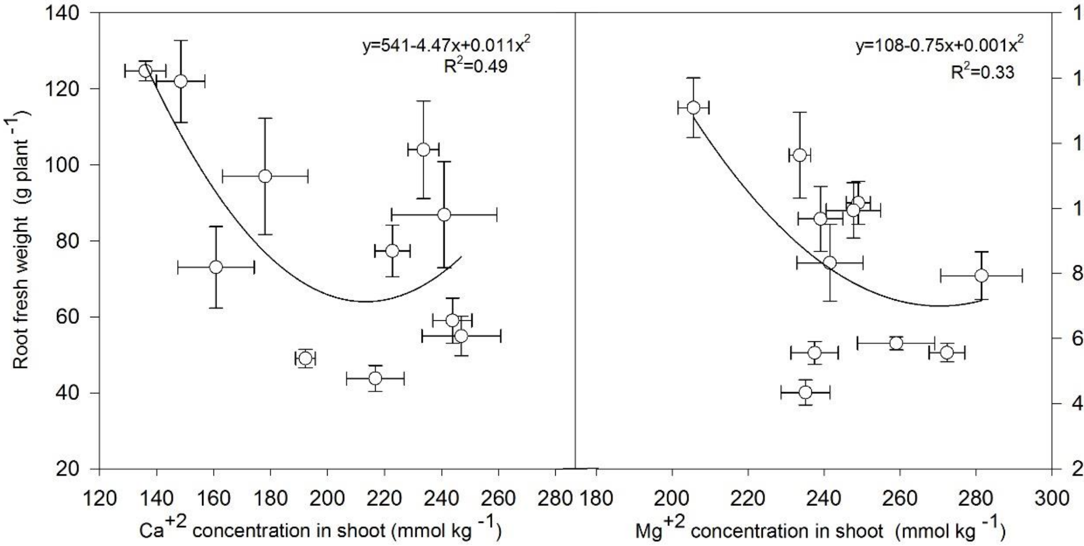

Figure 8. Correaltion between shoot calcium (Ca^{+2}) and magnesium (Mg^{+2}) concentration on root fresh weight and shoot dry weight in anthurium (*Anthurium andreanum* Lind) plants.

ARTÍCULO II

Anion proportion in the nutrient solution impacts the growth and nutrient status of anthurium (Anthurium andraeanum Linden ex. André.)

Anion proportion in the nutrient solution impacts the growth and nutrient status of anthurium (*Anthurium andraeanum* Linden ex. André.)

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Additional index words. tropical ornamental plants, nitrate, sulfate, phosphate, mixture experiments

Abstract. Anthurium is native to habitats characterized by low nutrient supply, however, when cultivated, it demands a complete fertilization program. The objective of the present study was to determine the effect of varying proportions of anions [nitrate ($NO_3^–$), phosphate ($H_2PO_4^–$) and sulphate ($SO_4^{2–}$)] in the nutrient solution on the growth and nutrient status of container grown anthurium. The effect of the anion proportion was modeled using mixture analysis. Plant growth increased when fertigated with solutions containing an anion proportion of 0.78: 0.12: 0.10, 0.20 : 0.12 : 0.68 and 0.80 : 0.02 : 0.18. The contour plots showed that optimum response may be achieved in two areas, an area with high $NO_3^–$ proportion (0.50 – 0.80) and an area with high $SO_4^–$, provided $H_2PO_4^–$ was high (0.09 – 0.12 for $H_2PO_4^–$ and 0.55 – 0.70 for $SO_4^{2–}$). The counter plots indicate that high $SO_4^{2–}$ proportions combined with low $NO_3^–$ and $H_2PO_4^–$ were detrimental and that optimum growth depends not only on N concentration, as it may be attained at either high or low $NO_3^–$. Nitrogen and S concentration was higher in plants fertigated with high $NO_3^–$ (0.55 – 0.80) and $SO_4^{2–}$ (0.40 – 0.70) solutions. Shoot P was higher when plants were fertigated with solutions of low (as long as NO_3^- was at proportions of 0.50 and SO_4^{2-} at 0.35) or high $H_2PO_4^–$ proportions (as long as $SO_4^{2–}$ proportion was at 0.35). At low concentration of S in the shoot, increasing S resulted in increasing shoot N, however,

further S increments in the shoot were associated with a decrease in N. Plants fertigated with the highest proportion of $H_2PO_4^{-}$ resulted in the lowest S concentrations despite some solutions contained high SO_4^{2-}, suggesting that $H_2PO_4^{-}$ counteracted the uptake of SO_4^{2-}. Nitrogen and S were predominantly diverted to the roots in control plants, however, when plants were fed with both high SO_4^{2-} and high $H_2PO_4^{-}$ solutions even more S was allocated to the roots, which explains the increased growth due to the lower S concentrations. In conclusion, the increased growth of anthurium was attained at either high or low NO_3^{-} proportion and it is able to cope with high SO_4^{2-} by avoiding the transport of S to the shoot, decreasing SO_4^{2-} intake, maintaining a favorable internal N/S and S/P proportion, and increasing P tissue concentration.

Anthurium (*Anthurium andraeanum* Linden ex. André.) is a tropical ornamental species of considerable beauty, which is cultivated for both the cut flower and potted plant markets. In its natural habitat, anthurium is considered an epiphytic or lithophytic species (Hull and Henny, 1995), and is usually found in habitats characterized by low light levels and low nutrient supply, typically in shaded conditions and on the trunks of trees, where the roots have no contact with the soil (Zotz and Hietz, 2001). Nutrients supply and availability, particularly nitrogen (N), have been reported to be key factors that determine anthurium growth, flower number, and quality/marketability (Chang et al., 2010).

Nitrogen is a major factor in determining final quality of anthurium plants (Conover and Henny, 1995). In some species of anthurium, including *A. acaule* and *A. cordatum*, similar N concentrations to that of terrestrial species have been reported, 1.87% and 2.33%, respectively (Zotz and Hietz, 2001). Li and Zhang (2002) reported high quality and maximum dry mass of anthurium plants fed with N concentrations ranging from 10 to 40 mg L^{-1}, with 20 mg L^{-1} N producing the highest quality.

Nonetheless, the interaction of N with other nutrients must also be considered when developing a feasible fertility program, as N may affect the availability and uptake of other ions. For example, it has been reported that high quality in *A. andraeanum* is obtained when fertilized at low N (1.85 g per 15 cm-pot per year) and high potassium (K) (1.39 to 3.07 g per 15 cm-pot per year) rates; conversely, plants fertilized with high N and K rates resulted in poor growth and marketability (Conover and Henny, 1995). Similarly, rapid growth was reported in anthurium when N and K were supplied at 8.9 and 3.2 mmol L^{-1}, respectively; however, when Ca was reduced from 2.3 to 1.2 mmol L^{-1}, a decrease in the length of the vegetative phase was observed along with an increase in flower production (Dufour and Guérin, 2005).

Therefore, the total nutrient concentration and the proportion of the ions dissolved in the nutrient solution have to be considered (Steiner, 1968) when defining an optimal fertility program. The mutual ion relations are also important for plant growth as an unbalanced combination may result in decreased biomass and yield due to the antagonistic relationships among ions (Ding et al., 2006; Jakobsen, 1993). There is limited information as to the effect of the nutrients proportion and interactions on the growth and marketability of anthurium, thus, the present study had the objective of determining the response of container grown anthurium plants to varying proportions of anions [nitrate (NO_3^-), phosphate ($H_2PO_4^-$) and sulphate (SO_4^{2-})] in the nutrient solution on the growth and nutrient status.

Materials and methods

Cultural conditions and plant material. The experiment was conducted under greenhouse at the Universidad Autónoma Agraria Antonio Narro, in Saltillo, Coah., México (25° 21’ 24.37” N latitude, 101° 02’ 05.45” W longitude; 1762 m above sea level). Environmental parameters were recorded (Watch Dog 1000 Series, Spectrum Technologies, Inc. Aurora, IL) throughout the study, recording an average daily temperature of 20°C (maximum 31.5°C, minimum 13.5°C), relative humidity 66% ± 20%, and photosynthetically active radiation at 177 µmol m^{-2} s^{-1}.

The growing medium consisted of a 1:1 mixture of sphagnum peat (PREMIER, Premier Tech, Toronto, Canada) (NO_3^-: 0.15 meq L^{-1}, $H_2PO_4^-$: 0.08 meq L^{-1}, SO_4^{2-}: 0.22 meq L^{-1}, K^+: 0.15 meq L^{-1}, Ca^{2+}: 1.18 meq L^{-1}, Mg^{2+}: 0.55 meq L^{-1}, HCO_3^-: 0.70 meq L^{-1}) and horticultural-grade perlite (HORTIPERL, Termolita, Monterrey, México). The medium pH was adjusted to 6.3 prior to transplanting to 17.8 cm black plastic standard pots. *Anthurium andraeanum* cv. Tropical plants (12-15 cm in height, with 2-3 young leaves) were transplanted into the medium on 17 Oct. 2014 and harvested on 20 Oct. 2015.

Nutrient solutions. The treatments consisted of eight nutrient solutions selected with Design Expert v. 9.0 (Stat Ease, Inc. Minneapolis, MN) (Table 1). Electrical conductivity and pH of the nutrient solutions was maintained at 2.0 dS m^{-1} and 5.5 – 6.0, respectively. The sum of anions in all the nutrient solutions was held constant at 20 meq L^{-1}. However, the proportions of NO_3^-, $H_2PO_4^-$ and SO_4^{2-} varied from 0.20 – 0.80, 0.02 – 0.12 and 0.10 – 0.70, respectively, in order to explore the area shown in Fig. 1. The control treatment corresponded to Steiner´s formulation, containing (meq L^{-1}): 12 NO_3^-, 1 $H_2PO_4^-$, 7 SO_4^{2-}, 9 Ca^{2+}, 7 K^+, and 4 Mg^{2+} (Steiner, 1973). Micronutrients in all the nutrient solutions were provided at the following concentrations (mg L^{-1}): 4 Fe-EDTA, 2 Mn-EDTA, 0.37 B, 0.32 Zn-EDTA, 0.16 Cu-EDTA, and 0.11 Mo. Plants were manually irrigated when the growing medium registered a moisture tension of 10 cb (Irrometer Model MLT, IRROMETER, Riverside, CA) adding enough solution to attain a leaching fraction of ~30%.

Assessment of plant growth and nutrient status. Plants were harvested 368 d after transplanting. Harvested plant material was separated into roots and shoots and rinsed twice with deionized water. Root volume was measured by the water displacement method in a graduated cylinder. Leaf area and spathe area were measured in an Area Meter (Model LI-3100C, LI-COR Inc. Lincoln, NE). Fresh mass of shoot and root were measured prior to drying in an oven at 70°C for 3 d. Dry tissues were then weighed, and ground to pass a 40 mesh filter (Mini Willey Mill, Thomas Scientific. Swedesboro, NJ).

Nitrogen concentration in plant tissues was determined using semi-micro Kjeldhal´s procedure. Phosphorus (P) and sulfur (S) concentrations were determined with inductively coupled plasma emission spectrometer (ICP-AES 725 Series Agilent; Mulgrave, Victoria, Australia) in samples digested in a mixture of H_2SO_4 and $HClO_4$ plus 1 mL of H_2O_2 for P analysis and in a mixture of HNO_3 and $HClO_4$ for S analysis.

Statistical design and analysis. The eight nutrient solutions with four replications (one pot per replication) were distributed in a randomized complete block design. Data were analyzed with SAS to conduct an analysis of variance and a multiple comparison test (Duncan´s procedure, $p < 0.05$). The effect of the NO_3^- : $H_2PO_4^-$: SO_4^{2-} proportion was modeled using mixture analysis with Design-Expert® v 9.0. The models selected were those with the highest R^2 and p-value, along with an adequate precision higher than 4.0 and a non-significant lack of fit, which indicate that the model can be used to predict the response of plants when used within the space on which it was designed (Fig. 1). A regression analysis was conducted when a significant response of plant growth or nutrient concentration in plant tissues was detected.

Results and discussion

*Growth and biomass. G*rowth was increased when plants were fertigated with solutions containing a NO_3^- : $H_2PO_4^-$: SO_4^{2-} proportion of 0.78 : 0.12 : 0.10, 0.20 : 0.12 : 0.68 and 0.80 : 0.02 : 0.18; in general, all parameters measured were significantly higher when compared to plants fertigated with Steiner´s nutrient solution (Table 2).

Mixture analysis allowed the identification of several parameters whose models can be used to explore the space area designed (Table 3). The integration of the predictions of each individual model allows the definition of specific areas in the contour plots that include the nutrient solutions on which a threshold optimum response may be achieved; in the present study, there were two areas of the explored space for highest leaf area (Fig. 2), shoot, root and total fresh (Fig. 3) and dry mass (Fig. 4):

a). An area with high proportions of NO_3^-: 0.50 – 0.80 for NO_3^-, 0.02 – 0.06 for $H_2PO_4^-$ and 0.10 – 0.35 for SO_4^{2-}

b). An area with high proportions of SO_4^- but provided the proportion of $H_2PO_4^-$ was high: 0.20 to 0.35 for NO_3^-, 0.09 – 0.12 for $H_2PO_4^-$ and 0.55 – 0.70 for SO_4^{2-}.

Similarly, spathe area and root volume were highest when NO_3^- proportion ranged from 0.45 – 0.60, $H_2PO_4^-$ proportion from 0.02 – 0.06 and SO_4^{2-} proportion from 0.27 – 0.43 (Fig. 2). The counter plots obtained with mixture analysis suggests that high proportions of SO_4^{2-} combined with low proportions of NO_3^- and $H_2PO_4^-$ were detrimental for plant growth as fresh (Fig. 3) and dry mass (Fig. 4) were decreased.

These trends were comparable to those reported in anthurium by Dufour and Guérin (2005) that reported that a higher concentration of N, 8.9 mmol L^{-1}, was associated with increased growth. In our study, according to the mixture analysis, the high concentrations of N for optimum growth ranged from 10 – 16 meq L^{-1} (NO_3^- proportions from 0.50 to 0.80), which are considerably higher than those assessed by Dufour and Guérin (2005). Furthermore, the models also indicate that a low NO_3^- proportion (0.20 – 0.35) or concentration (4.0 to 7.0 meq L^{-1}) may also be associated with growth enhancement provided a relatively high $H_2PO_4^-$ proportion is maintained, from 0.09 – 0.12 (1.8 to 2.4 meq L^{-1}), regardless of the high SO_4^{2-} proportion or concentration (proportion from 0.55 – 0.70, 11.0 to 14.0 meq L^{-1}). This may be because of the low N concentrations at which we observed optimum growth (4.0 to 7.0 meq L^{-1}) were similar to the high concentrations reported by Dufour and Guérin (2005) and because of the greater supply of P, a nutrient which is usually found to be deficient in epiphytic plants (Zotz, 2004).

Our results suggest that optimum growth of anthurium depended not only on N concentration, as it may be attained at either high or low NO_3^-, but also on the proportion in which it is combined with $H_2PO_4^-$ and SO_4^{2-}. Similarly, Takano (1987) suggested that the NO_3^-, $H_2PO_4^-$ and SO_4^{2-} proportion and the proportion of SO_4^{2-} and $H_2PO_4^-$ may be useful in adjusting the uptake of NO_3^-, and thereby improving the quality of edible vegetables.

Nutrient status. Kleiber and Komosa (2010) reported that N, P and S in anthurium leaves should range from 907 – 1329, 94 – 145 and 69 – 141 mmol kg^{-1}, respectively. In the present study, shoot and root N, P and S concentration were significantly affected by the NO_3^- : $H_2PO_4^-$: SO_4^{2-} proportions in the nutrient solution (Table 4); in the roots, N, P, and S were similar to those reported for the leaves by Kleiber and Komosa (2010), while in the shoot, they were within those ranges only for some treatments (Table 4). Our results were similar to those reported by Chang et al. (2012) indicating that high N (7.5 and 11.3 meq L^{-1}) was associated with improved dry mass, leaf area, and number of flowers in anthurium, when compared to plants fertigated with lower or higher N levels (5.6 and 15.0 meq L^{-1}).

Increasing the proportions of NO_3^-, $H_2PO_4^-$ and SO_4^{2-} resulted in increased concentration of N, P and S in anthurium plants. Plants fed with solutions containing the highest SO_4^{2-} proportions resulted in plants with the highest S content at a whole plant level, except when plants were fed with high $H_2PO_4^-$ (NO_3^- : $H_2PO_4^-$: SO_4^{2-} proportion of 0.20 : 0.12 : 0.68). A similar trend in SO_4^{2-} uptake was reported by López et al. (2002) in tomato seedlings (*Solanum lycopersicon* L.), which is in line with reports by Rennenberg (1984) suggesting that avoidance of S uptake is not a mechanism used by plants under external or internal SO_4^{2-} excess, being the influx of excess S was more probable than restricted uptake (Rennenberg, 1984).

Dufour and Clairon (1997) reported that adequate supply of N for anthurium is between 7.5 and 8.9 meq L^{-1}, as lower concentrations may reduce growth, affect the length of the vegetative phase, and produce flowers of low quality. In our current study, we observed that anthurium plants may grow even at lower NO_3^- proportions and concentrations, 0.20 and 4.0 meq L^{-1}, provided $H_2PO_4^-$ is increased to counteract the increase in SO_4^{2-}.

Anion interactions. Fageria and Oliveira (2014) suggested that information focused on the interactions among nutrients is of utmost importance when formulating a balanced supply of fertilizers to cultivated plants. Interactions among nutrients occur when the supply of one nutrient influences the uptake and utilization of another one (Fageria, 2001). In the current study, the interactions among the anions resulted in consistent trends and were modeled with mixture analysis (Table 5). The explored area showed that N and S tended to concentrate, for both, shoots (Fig. 5) and roots (Fig. 6), when plants were fertigated with solutions containing high proportions of $NO_3^–$ (0.55 – 0.80) and $SO_4^{2–}$ (0.40 – 0.70). Phosphorus concentration in the shoots was higher when plants were fertigated with solutions of low (as long as NO_3^- was at proportions of 0.50 and SO_4^{2-} at 0.35) or high $H_2PO_4^–$ proportions (as long as $SO_4^{2–}$ proportion was at 0.35) (Fig. 5). In the roots, increasing P concentrations were associated with increasing $H_2PO_4^–$ proportions (Fig. 6).

Nitrogen is a constituent of all the amino acids while S is a constituent in two of them, cysteine and methionine; therefore, as N and S are both part of proteins, there is a close relationship between their assimilation (Hawkesford et al., 2012). The uptake of N and S is well coordinated, in that, for example, a deficiency of one may cause a decrease in the assimilation of the other one (Kopriva and Rennenberg, 2004; Kruse et al., 2007). A close relationship between N and S has been reported in several plant species; for example, in wheat (*Triticum aestivum* L.) (Salvagiotti et al., 2009) and legumes (Scherer, 2001), increasing S fertilization under S deficiency conditions resulted in improved N use efficiency and uptake, however, in tomato and cabbage (*Brassica oleracea* var. *capitata* L.), N uptake was inhibited by high concentrations of $SO_4^{2–}$ (Takano, 1987). Sulfur deficiency in wheat has also been related to lower sulfur-amino acids content and reduced yield (Järvan et al., 2008).

In the present study, the association between N and S was also observed since at low shoot concentration, increasing S resulted in increasing shoot N concentration (Fig. 7), however, further S increments in the shoot were associated with a decrease in shoot N

(Fig. 7). The decreased N concentration as a result of the high S concentration in the shoots may explain the potentially toxic effects of SO_4^{2-} observed in our current study, as indicated by the lower root, shoot, and total plant fresh and dry mass at high S concentrations (Fig. 8).

Nitrogen and S in shoots and roots were highest when the proportion of the respective anion increased in the nutrient solution (Figs. 5-6), furthermore, SO_4^{2-} uptake rate was maintained as indicated by the high S concentration in the shoots and roots at high SO_4^{2-} proportions (Figs. 5-6), while shoot S concentration was low even at high SO_4^{2-} proportions as long as the proportion of $H_2PO_4^-$ in the nutrient solution and the concentration of P in the shoot were high (Fig 5). Plants fertigated with nutrient solutions containing NO_3^-, $H_2PO_4^-$ and SO_4^{2-} at proportions of 0.20 : 0.12 : 0.68 (Table 4) resulted in growth promotion (Table 2).

Anthurium plants fertigated with solutions containing the highest proportion of $H_2PO_4^-$ resulted in shoots and roots with the lowest S concentration despite some of those nutrient solutions were formulated with very high SO_4^{2-} proportions (Table 2), suggesting that high $H_2PO_4^-$ proportions counteracted the uptake of SO_4^{2-}. This hypothesis is supported by reports indicating that SO_4^{2-}-induced salinity has a more negative impact on the growth of *Brassica rapa* L. at lower concentration of P (Reich et al., 2017), which also suggests that higher $H_2PO_4^-$ proportion may reduce the negative impact of SO_4^{2-} on $H_2PO_4^-$ uptake.

Internal nitrogen/sulfur and phosphorus/sulfur proportion. High S concentrations in plant tissues (Fig. 8) affected the internal N/S and S/P proportions. Our results showed that a higher internal N/S proportion and a lower internal S/P proportion were associated with higher shoot fresh mass (Fig. 9). Similarly, increasing S shoot concentration was associated with poor growth, which is related to its effect on the reduction in the N/S proportion and in the increase in the S/P proportion.

At a whole plant level, Cram (1990) reported that the N/S proportion for optimum growth in plants is 20/1, whereas for clover (*Trifolium repens* L.), the optimum S/P proportion ranged from 0.81 – 0.93 (Morton et al., 1998). In the present study, optimum growth of anthurium plants was observed when the N/S and S/P proportion ranged from 31/1 – 38/1 and 0.33/1 – 0.80/1, respectively (Fig. 9). These results suggest that for optimum growth, nutrient solutions must contain high proportions of NO_3^- and low SO_4^{2-} in order for the plant to have a high internal N/S proportion. Alternatively, a high proportion of SO_4^{2-} in the nutrient solution may render acceptable plant growth as long as the proportion of $H_2PO_4^-$ is higher, in order for the plant to maintain a low internal S/P proportion.

Effect of the external anion proportion on N, P and S allocation. The allocation of N, P, and S within the plant was affected by the NO_3^- : $H_2PO_4^-$: SO_4^{2-} proportion in the nutrient solution. Nitrogen was predominantly diverted to the roots in control plants, while the allocation to the shoots increased in plants fertigated with lower proportions of NO_3^- (Fig. 10). The relatively higher allocation of N to the shoots of plants under limited NO_3^- supply suggests that this nutrient was transported from the roots to promote shoot growth under insufficiency conditions. Despite the increased S concentration in plant tissues with increasing SO_4^{2-} proportions (Table 4), most of the S was allocated to the roots (Fig. 10); this is in agreement with results reported for tomato seedlings, in that increasing SO_4^{2-} supply to S-deficient plants results in increased transport rate of SO_4^{2-} to the shoot, however, when the supply of SO_4^{2-} was high, the transport rate did not increase (López et al., 2002).

In the present study, when anthurium plants were fed with both high SO_4^{2-} and high $H_2PO_4^-$, even more S was allocated to the roots than to the shoots (Fig. 10), as observed in plants fertigated with solutions with a NO_3^- : $H_2PO_4^-$: SO_4^{2-} proportion of 0.20 : 0.12 : 0.68. The restricted S translocation to the shoot when $H_2PO_4^-$ was at high proportions may explain the increased growth of these plants as lower S concentrations was associated with increased shoot fresh and dry mass accumulation (Fig. 8).

These results suggest that anthurium plants were able to cope with high SO_4^{2-} in the nutrient solution by:

a). Avoiding the transport of S to the shoot (Fig. 10),

b). Decreasing SO_4^{2-} intake (Table 4),

c). Maintaining a favorable internal N/S proportion (Fig. 9),

d). Maintaining a favorable internal S/P proportion (Fig. 9),

e). Increasing P tissue concentration as a result of high proportions of $H_2PO_4^-$ in the nutrient solution.

Anion uptake selectivity. In spite of the differences in nutrient concentration, plant internal NO_3^- : $H_2PO_4^-$: SO_4^{2-} proportion was not affected by the external anion ratios, as indicated by the internal nutrient ratios in the shoots and roots were located in a very specific area (Fig. 11). This suggests that anthurium plants regulate the accumulation of anions according to its internal demands. Steiner (1973) reported similar trends in tomato plants, concluding that, regardless of the ratio in the nutrient solution, tomato has a strong selective capacity for cations and anions uptake at a given ratio. In the current study, the location of the area for the internal anion ratio shown in Fig. 11, suggests that anthurium was highly selective to exclude SO_4^{2-}, as this nutrient was at much lower concentrations than that of the external solutions. Similarly, anthurium plants were able to adjust their uptake of NO_3^- as the internal proportion was maintained at relatively high concentration regardless of the external ratio (Fig. 11). In contrast, the uptake of $H_2PO_4^-$ was not as selective, as the internal and external ratios were very similar (Fig. 11).

In conclusion, increased growth of anthurium plants was attained at either high or low NO_3^- proportions. Furthermore, we suggest that at low NO_3^-, the high $H_2PO_4^-$ counteracted the deleterious effect of high SO_4^{2-} proportions on P tissue concentration. Increasing S concentration in plant tissues was associated with reduced growth, however, excess SO_4^{2-} uptake was prevented when P status in the plants was increased when $H_2PO_4^-$ proportions were augmented, resulting in lower S tissue concentrations and improved growth. Our results also suggest that anthurium plants were able to cope with high SO_4^{2-} when $H_2PO_4^-$ in the nutrient solution was increased through limiting its transport to the shoot, which in turn resulted in favorable N/S and S/P internal proportions. The internal anion proportion was not affected by the NO_3^- : $H_2PO_4^-$: SO_4^{2-} proportions in the nutrient solution, demonstrating that anthurium possesses a high selective capacity for nutrient uptake and allocation/partitioning.

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Table 1. Proportion of anions and cations in the nutrient solutions assessed[z].

Nutrient Solution	NO_3^-	$H_2PO_4^-$	SO_4^{-2}	K^+	Ca^{+2}	Mg^{+2}
1	0.43	0.05	0.52	0.42	0.25	0.33
2	0.80	0.02	0.18	0.48	0.51	0.01
3	0.78	0.12	0.10	0.08	0.59	0.33
5	0.20	0.12	0.68	0.65	0.25	0.10
5	0.49	0.12	0.39	0.09	0.68	0.23
6	0.28	0.02	0.70	0.37	0.47	0.17
7	0.36	0.10	0.55	0.22	0.57	0.21
8 (Control)	0.60	0.05	0.35	0.35	0.45	0.20

[z] Total sum of anions, and cations, was held constant at 20 meq L^{-1}; thus, to determine the chemical composition of a given nutrient solution each proportion should be multiplied by 20. For example, solution number 1 has NO_3^- at 0.43 × 20 = 8.6 meq L^{-1}, $H_2PO_4^-$ at 0.05 × 20 = 1.0 meq L^{-1} and SO_4^{2-} at 0.52 × 20 = 10.4 meq L^{-1}.

Table 2. Effect of the NO_3^- : $H_2PO_4^-$: SO_4^{2-} proportion in the nutrient solution on growth parameters of anthurium (*Anthurium andraeanum* Linden ex André) plants.

NO_3^-	$H_2PO_4^-$	SO_4^{-2}	Spathe area (cm^2)	Leaf area (cm^2)	Root volume (cm^3)	Shoot fresh mass (g)	Root fresh mass (g)	Shoot dry mass (g)	Root dry mass (g)	Total fresh mass (g)	Total dry mass (g)
Proportion											
0.43	0.05	0.53	119bc	534b	53cd	52.6bc	55cd	5.85bc	7.26cd	108c	13.6b
0.80	0.02	0.18	145abc	770a	107b	83.5a	91abc	10.9a	8.93bc	178ab	21.1a
0.78	0.12	0.10	155ab	799a	118b	81.8a	111ab	9.93ab	11.1ab	193a	20.7a
0.20	0.12	0.68	169a	790a	151a	85.7a	122a	9.94ab	12.7a	208a	21.5a
0.49	0.12	0.39	104cd	563b	75c	60.6ab	68bcd	6.75abc	7.55cd	129bc	15.4b
0.28	0.02	0.70	149abc	430b	52cd	36.9bc	44d	8.33abc	5.49d	81c	11.5b
0.36	0.10	0.55	62de	410b	43d	47.7bc	49cd	5.56bc	6.17cd	97c	10.9b
0.60	0.05	0.35	42e	412b	44d	28.4c	73bcd	4.35c	6.89cd	101c	11.9b

Table 3. Models that estimate the spathe and leaf area, root volume and shoot, root, and total fresh and dry mass of anthurium (*Anthurium andraeanum* Linden Ex André) plants in response to the NO_3^- : $H_2PO_4^-$: SO_4^{2-} proportion in the nutrient solution.

Growth parameter^z	Model	P <	Lack of Fit	R^2	Adequate precision
Spathe area (cm^2) =	$+118NO_3+40935H_2PO_4+90.3SO_4-45838(NO_3\times H_2PO_4)+1063(NO_3\times SO_4)-44632(H_2PO_4\times SO_4)-13956(NO_3\times H_2PO_4\times SO_4)$	0.01	0.03	0.79	10.3
Leaf area (cm^2) =	$+1696NO_3+62612H_2PO_4+692SO_4-77957(NO_3\times H_2PO_4)-1907(NO_3\times SO_4)-66479(H_2PO_4\times SO_4)$	0.01	0.04	0.66	9.08
Root volume (cm^3) =	$+159NO_3+29916H_2PO_4-156SO_4-34313(NO_3\times H_2PO_4)+928(NO_3\times SO_4)-30293(H_2PO_4\times SO_4)-11946(NO_3\times H_2PO_4\times SO_4)$	0.01	0.67	0.91	16.4
Shoot fresh mass (g) =	$+192NO_3+8011H_2PO_4+72.8SO_4-9839(NO_3\times H_2PO_4)-249(NO_3\times SO_4)-8487(H_2PO_4\times SO_4)$	0.01	0.03	0.61	7.87
Root fresh mass (g) =	$+217NO_3+2941H_2PO_4+71.7SO_4-4245(NO_3\times H_2PO_4)-351(NO_3\times SO_4)-2240(H_2PO_4\times SO_4)$	0.02	0.18	0.51	5.88

Shoot dry mass (g) =	$+27.7NO_3+1430H_2PO_4+17.3SO_4-1739(NO_3\times H_2PO_4)-38.5(NO_3\times SO_4)-1614(H_2PO_4\times SO_4)$	0.01	0.50	0.55	7.34
Root dry mass (g) =	$+5.79NO_3+1675H_2PO_4-15.1SO_4-1868(NO_3\times H_2PO_4)+92(NO_3\times SO_4)-1594(H_2PO_4\times SO_4)-1028(NO_3\times H_2PO_4\times SO_4)$	0.01	0.05	0.71	8.54
Total fresh mass (g) =	$+395NO_3+13593H_2PO_4+102SO_4-17175(NO_3\times H_2PO_4)-383(NO_3\times SO_4)-13982(H_2PO_4\times SO_4)$	0.01	0.12	0.76	11.1
Total dry mass (g) =	$+44.5NO_3+2091H_2PO_4+13.1SO_4-2582(NO_3\times H_2PO_4)-25.3(NO_3\times SO_4)-2262(H_2PO_4\times SO_4)$	0.01	0.13	0.70	9.93

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[z] To estimate any growth parameter, enter the proportion of NO_3^-, $H_2PO_4^-$ and SO_4^{2-} in the model and multiply them by the correspondent coefficient. The sum of the proportions of the three anions must be equal to 1.

Table 4. Effect of the NO_3^- : $H_2PO_4^-$: SO_4^{2-} proportion in the nutrient solutions on the concentration of nitrogen (N), phosphorus (P) and sulfur (S) in shoots and roots of anthurium (*Anthurium andraeanum* Linden ex André) plants.

Nutrient solution			Shoot			Root		
NO_3^-	$H_2PO_4^-$	SO_4^{-2}	N	P	S	N	P	S
Proportion			mmol kg^{-1}	mmol kg^{-1}	mmol kg^{-1}	mmol kg^{-1}	mmol kg^{-1}	mmol kg^{-1}
0.43	0.05	0.53	1342ab	52.4bc	63.7a	1325bc	150cd	91.4bc
0.80	0.02	0.18	1428ab	47.7c	37.2c	1556a	95e	81.9c
0.78	0.12	0.10	1419ab	56.7bc	45.8bc	1644a	230ab	85.1c
0.20	0.12	0.68	1231b	111.0a	36.4c	1242c	252a	89.0bc
0.49	0.12	0.39	1500a	61.8b	49.6abc	1431abc	179bc	80.5c
0.28	0.02	0.70	1338ab	47.3b	60.6ab	1238c	88e	106.0ab
0.36	0.10	0.55	1438ab	58.4bc	55.2ab	1508ab	188bc	112.0a
0.60	0.05	0.35	1250b	53.3bc	65.6a	1525ab	116de	91.7bc

Table 5. Models that estimate nitrogen (N), phosphorus (P) and sulfur (S) concentration in shoots and roots of anthurium (*Anthurium andraeanum* Linden ex André) plants in response to the NO_3^{-} : $H_2PO_4^{-}$: SO_4^{2-} proportion in the nutrient solution.

Nutrient concentration (mmol kg^{-1})^z	Model	P <	Lack of Fit	R^2	Adequate precision
Root					
N =	$+2534NO_3-135050H_2PO_4+2923SO_4+148441(NO_3\times H_2PO_4)-9768(NO_3\times SO_4) + 137289(H_2PO_4\times SO_4)+85850(NO_3\times H_2PO_4\times SO_4)$	0.01	0.44	0.74	10.46
P =	$+59.0NO_3+1317H_2PO_4+80.8SO_4$	0.01	0.11	0.65	11.1
S =	$+163NO_3-15221H_2PO_4+346SO_4+16786(NO_3\times H_2PO_4)-1072(NO_3\times SO_4)+15387(H_2PO_4\times SO_4)+8283(NO_3\times H_2PO_4\times SO_4)$	0.01	0.77	0.72	8.3
Shoot					
N =	$+2030NO_3-21659H_2PO_4+2440SO_4+20061(NO_3\times H_2PO_4)-5201(NO_3\times SO_4)+12316(H_2PO_4\times SO_4)+60648(NO_3\times H_2PO_4\times SO_4)$	0.01	0.10	0.54	6.23
P =	$-28.7NO_3+9569H_2PO_4-135SO_4-10014(NO_3\times H_2PO_4)+833(NO_3\times SO_4)-8145(H_2PO_4\times SO_4)+-9120(NO_3\times H_2PO_4\times SO_4)$	0.01	0.29	0.88	16.8

S =	$+1.55NO_3 - 3161H_2PO_4 + 49.80SO_4 + 3962(NO_3 \times H_2PO_4) + 99.7(NO_3 \times SO_4) + 3350(H_2PO_4 \times SO_4)$	0.01	0.88	0.63	7.29

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[z] To estimate any nutrient concentration, enter the proportion of NO_3^-, $H_2PO_4^-$ and SO_4^{2-} in the model and multiply them by the correspondent coefficient. The sum of the proportions of the three anions must be equal to 1.

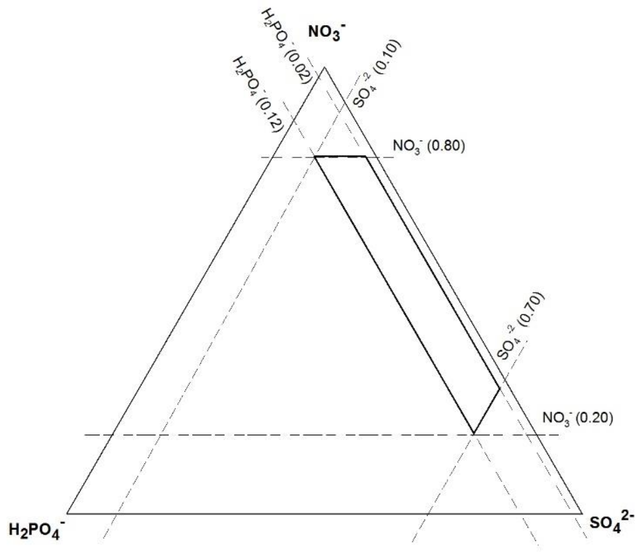

Figure 1. Design points corresponding to the mixtures of NO_3^-, $H_2PO_4^-$ and SO_4^{2-} the nutrient solutions. The lines demarcate the minimum and maximum proportion of each anion.

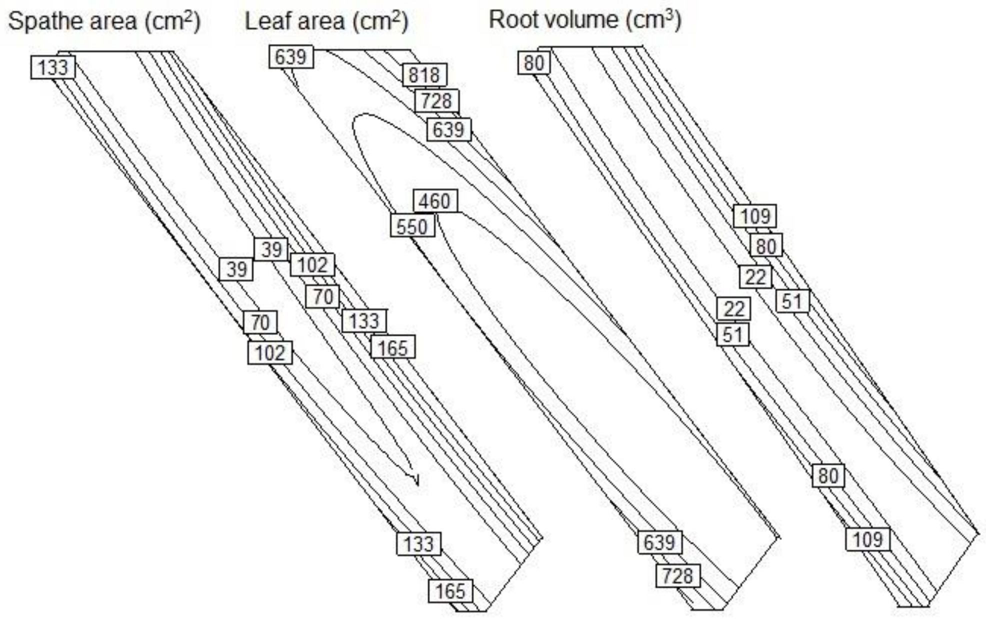

Figure 2. Counter plots showing the effect of the NO_3^-, $H_2PO_4^-$ and SO_4^{2-} proportion in the nutrient solution on spathe area, leaf area and root volume in anthurium (*Anthurium andraeanum* Linden ex André) plants.

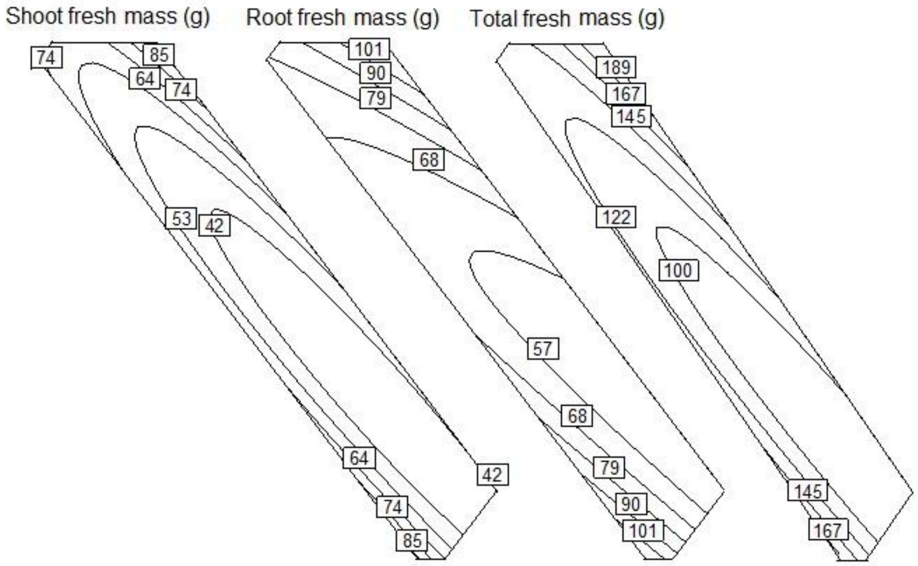

Figure 3. Counter plots showing the effect of the NO_3^-, $H_2PO_4^-$ and SO_4^{2-} proportion in the nutrient solution on shoot, root and total fresh mass in anthurium (*Anthurium andraeanum* Linden ex André) plants.

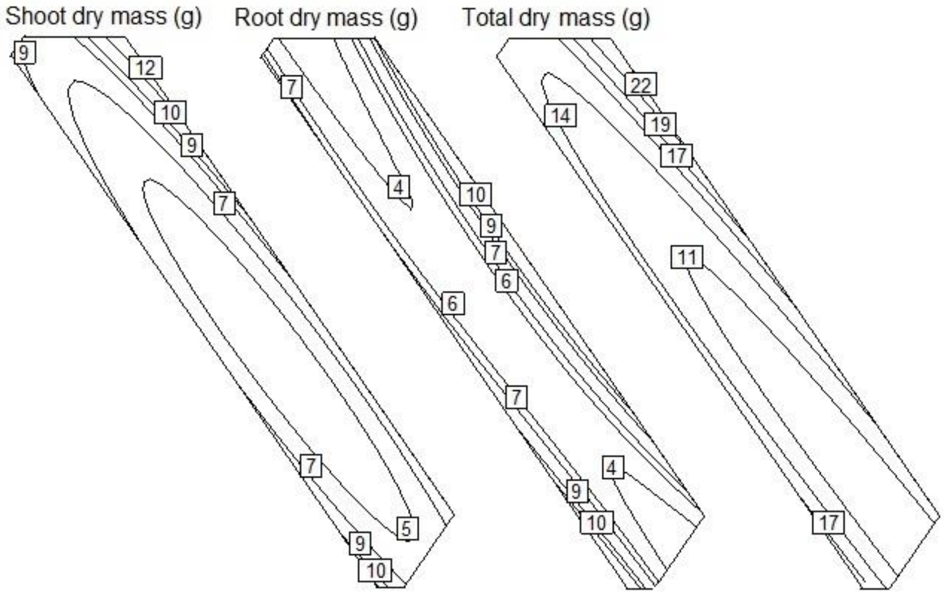

Figure 4. Counter plots showing the effect of the NO_3^-, $H_2PO_4^-$ and SO_4^{2-} proportion in the nutrient solution on shoot, root and total dry mass in anthurium (*Anthurium andraeanum* Linden ex André) plants.

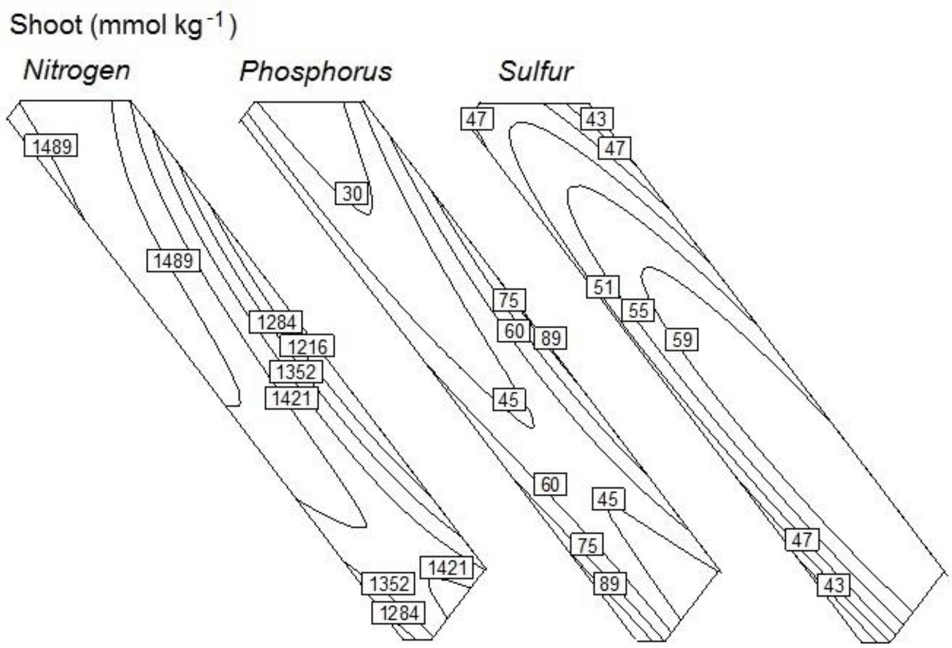

Figure 5. Counter plots showing the effect of the NO_3^-, $H_2PO_4^-$ and SO_4^{2-} proportion in the nutrient solution in shoot nitrogen (N), phosphorus (P) and sulfur (S) concentration in anthurium (*Anthurium andraeanum* Linden ex André) plants.

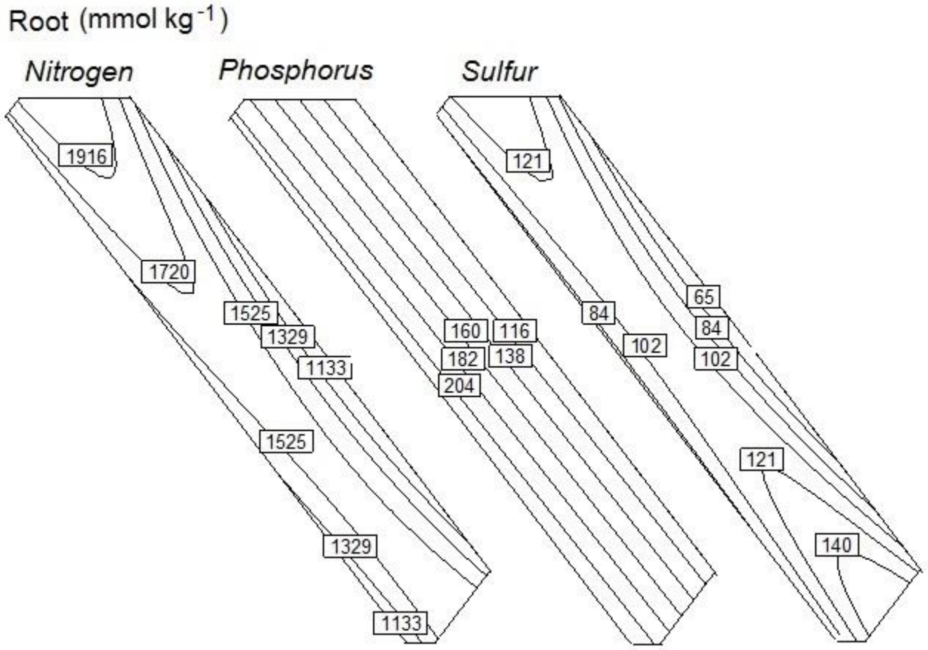

Figure 6. Counter plots showing the effect of the NO_3^-, $H_2PO_4^-$ and SO_4^{2-} proportion in the nutrient solution in root nitrogen (N), phosphorus (P) and sulfur (S) concentration in anthurium (*Anthurium andraeanum* Linden ex André) plants.

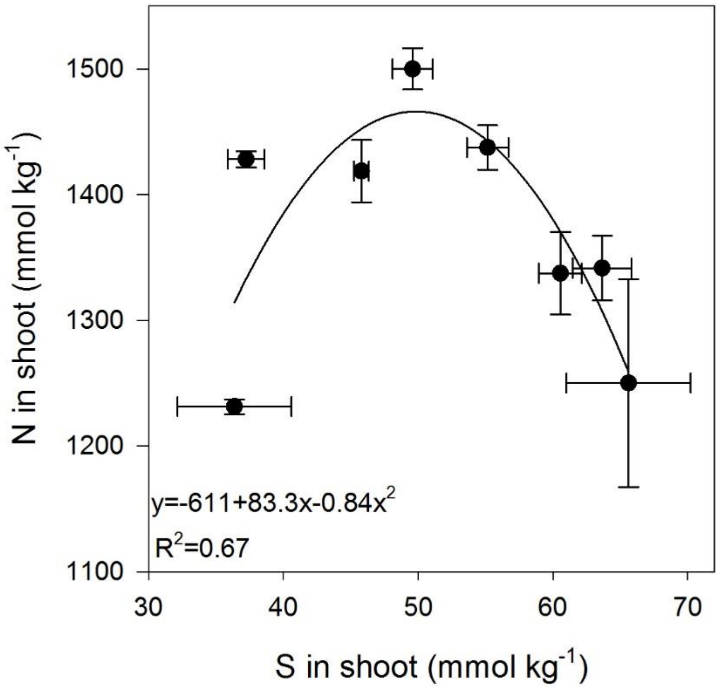

Figure 7. Relationship between the concentration of nitrogen (N) and sulfur (S) in shoots of anthurium (*Anthurium andraeanum* Linden ex André) plants.

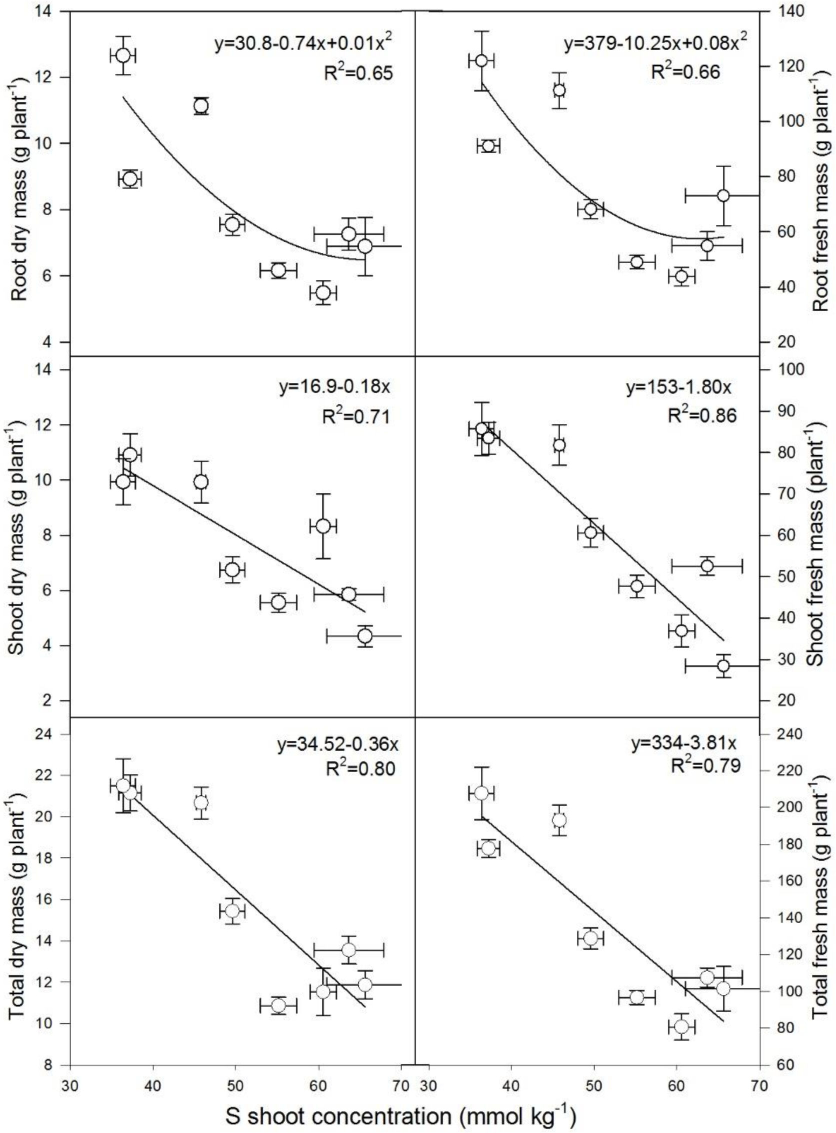

Figure 8. Correlation between shoot and root sulfur concentration on fresh weight and dry mass of shoots in anthurium (*Anthurium andraeanum* Linden ex André) plants.

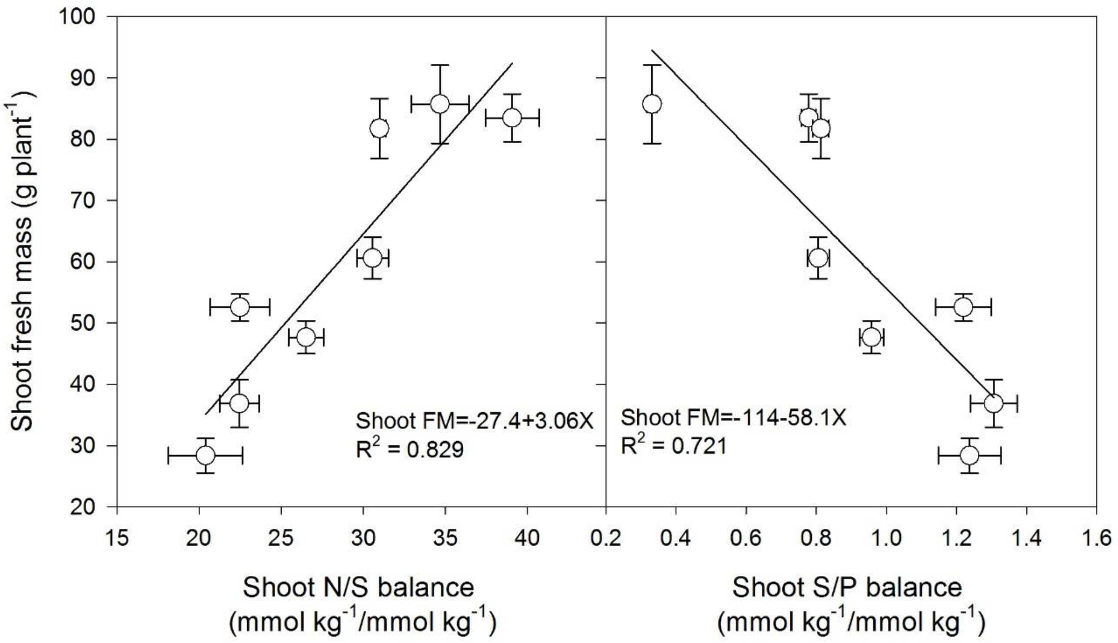

Figure 9. Correlation between shoot internal N/S, S/P proportion and shoot fresh mass in anthurium (*Anthurium andraeanum* Linden ex André) plants.

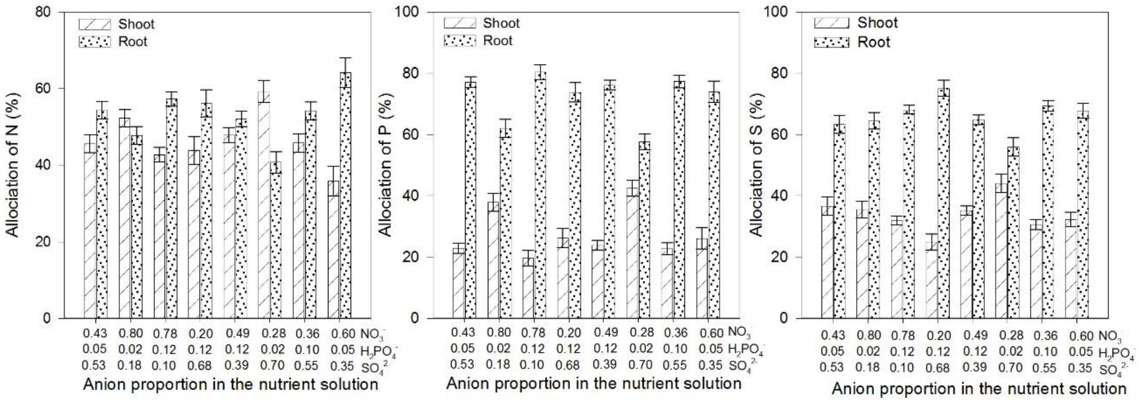

Figure 10. Relative distribution of nitrogen (N), phosphorus (P) and sulfur (S) in shoots and roots of anthurium (*Anthurium andraeanum* Linden ex André) plants.

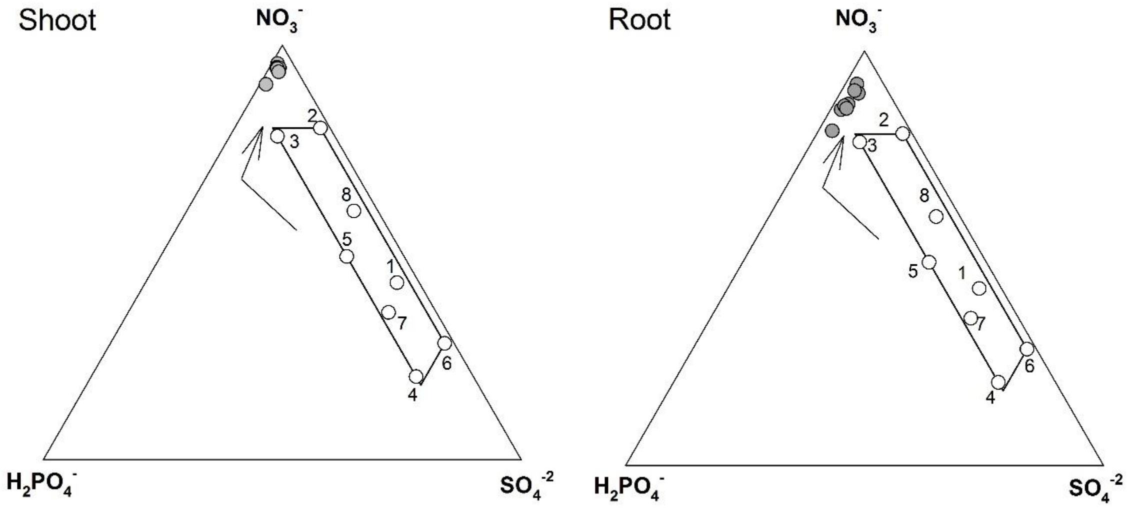

Figure 11. Relationship between the NO_3^-, $H_2PO_4^-$ and SO_4^{2-} proportion in the nutrient solution (while symbols) with the NO_3^-, $H_2PO_4^-$ and SO_4^{2-} proportion (grey symbols) in the shoot and root of anthurium (*Anthurium andraeanum* Linden ex André) plants. Numbers indicate the treatment nutrient solution as shown in Table 1. Data for shoot and root balance calculated on meq kg^{-1}.

CONCLUSIONES

La modificación del balance de aniones y cationes en la solución nutritiva permitió establecer rangos específicos de K^+: Ca^{2+}: Mg^{2+} y NO_3^- : $H_2PO_4^-$: SO_4^{2-} con los cuales se obtener mejores características morfológicas en las plantas de anturio cultivadas en maceta. La solución optima puede contener proporciones muy variadas de K^+, nivel medio 4.8-8.8 meq L^{-1}, nivel alto 10.8-13.0 meq $L^{-1,}$ Ca^{2+} alto (10.8-13.6 meq L^{-1}) y Mg^{2+} bajo (0.02-0.16 meq L^{-1}), ó Ca^{2+} bajo (5.0-5.8 meq $L^{-1)}$ y Mg^{2+} alto (2.0-2.2 meq L^{-1}). En cuanto a aniones un aumento en el crecimiento se obtuvo a baja (4.0 meq L^{-1}) o alta (15.6-16 meq L^{-1}) proporción de NO_3^-, amplio rango de $H_2PO_4^-$ (0.4-2.4 meq L^{-1}) y bajo (2.0-3.6 meq L^{-1}) o alto (13.6 meq L^{-1}) nivel de SO_4^{-2}.

Se observó que el balance de cationes y aniones interno no se vio afectado al modificar las proporciones de K^+: Ca^{+2}: Mg^{+2} y NO_3^- : $H_2PO_4^-$: SO_4^{2-} en la solución nutritiva, lo que demuestra que el anturio posee una alta capacidad selectiva para estos iones.

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