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Wpływ podłoża z miskanta na wzrost i rozwój wybranych gatunków bylin i krzewów ozdobnych

Rozprawa w formie hybrydowej

The influence of Miscanthus based media on the growth and development of selected perennials and ornamental shrubs

Praca doktorska

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pod kierunkiem

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Spis treści

1. Przegląd literatury

Produkcja ogrodnicza przechodzi nieustanne zmiany, które przede wszystkim są determinowane przez zwiększającą się populację ludności, co jednocześnie generuje zwiększone zapotrzebowanie na rośliny jadalne i ozdobne. Zmiany klimatyczne i działalność człowieka również nie są obojętne dla tej gałęzi przemysłu i skutkują przeniesieniem niektórych upraw pod osłony w celu możliwości kontrolowania warunków wzrostu roślin i zmniejszenia strat plonów powodowanych nieprzewidywalnością przebiegu pogody, a także ze względu na możliwość ograniczenia zanieczyszczeń, zwłaszcza na terenach zurbanizowanych (Gomez i in. 2019). Przykładem takiego rozwiązania jest uprawa pojemnikowa, która pozwala na zastosowanie podłoża dopasowanego do wymagań konkretnego gatunku pod względem właściwości fizyko-chemicznych, co dodatkowo niweluje problem związany z jakością dostępnych gleb, dzięki czemu możliwa jest maksymalizacja plonu i jego jakości (Barrett i in. 2016).

Przewidywane zapotrzebowanie na podłoża ogrodnicze może zwiększyć się nawet dwukrotnie na przestrzeni kolejnych 20 lat (Block i in. 2021). Dodatkowym problemem staje się dostępność stosowanych do tej pory podłoży ogrodniczych, wynikająca ze zwiększonej świadomości ekologicznej, jak również aspektów ekonomicznych. Dostępność torfu jako jednego z najdłużej i najpowszechniej stosowanych komponentów podłoży, zmniejsza się ze względu na ograniczenie jego wydobycia związanego z wartością ekologiczną torfowisk wysokich i ich ochroną prawną, jak również z emisją dwutlenku węgla podczas eksploatacji torfowisk (Barkham 1993, Robertson 1993), a w konsekwencji także rosnące ceny torfu (Caron i in. 2015). Kolejnym rodzajem podłoży ogrodniczych jest włókno kokosowe ma parametry fizyczne najbardziej zbliżone do torfu, stąd też często stosowane jest jako jego zamiennik (Berutti i Scariot 2011, Rangel i in. 2006). Jako że największym producentem włókna kokosowego są Indie (Carlile i in. 2015), ślad węglowy związany z transportem tego podłoża staje się kwestią problematyczną. W kontekście stosowania włókna koksowego kolejnym wyzwaniem przy produkcji roślinnej jest wysokie zasolenie tego materiału i inne zanieczyszczenia (Abad i in. 2002); przy czym dodatkowe analizy i wypłukiwanie nadmiaru soli mogą zwiększyć nakłady produkcji.

Kolejnym dostępnym zamiennikiem torfu jest kora i materiały pochodzenia drzewnego. Najczęściej wykorzystuje się korę i drewno sosnowe (Jackson i in. 2009), rzadziej z daglezji zielonej (Zazirska i in. 2009), jałowca wirginijskiego czy żółtnicy pomarańczowej (Starr i in. 2013). Ogólnodostępne są również komercyjne podłoża na bazie włókna drzewnego (Smith i in. 2017). Chociaż komponenty pochodzenia drzewnego sprawdzają się w uprawie pojemnikowej, ich dostępność w dużej mierze zależy od stanu przemysłu drzewnego, a sama wycinka drzew jest niepożądana z ekologicznego punktu widzenia.

Jak zaznaczyli Barrett i in. (2016), materiały używane do produkcji zrównoważonych podłoży powinny być wyselekcjonowane z uwzględnieniem zarówno ich ekonomicznych, jak i ekologicznych aspektów. Oprócz tego, materiały te powinny charakteryzować się łatwością praktycznego zastosowania w uprawie i jakością równą bądź lepszą od obecnie dostępnych podłoży, jak również uwzględniać ekologiczny aspekt zrównoważonego rozwoju podczas pozyskiwania tych materiałów. Stąd też szeroki wachlarz materiałów odpadowych, które testowane były jako podłoża bądź dodatki do podłoży, zarówno w świeżej jak i kompostowanej formie, w uprawie roślinnej, m.in.: łuski ryżowe (Bonaguro i in. 2017), wytłoczyny z winogron (Diaz-Perez i Comacho-Ferre 2010) oraz oliwek (Garcia-Gomez i in. 2002), odpady z gorzelni i browarów (Bustamante i in. 2008, Garcia-Gomez i in. 2002), łupiny słonecznika (Gonzales Matute i in. 2010) czy łupiny z orzechów włoskich (Dede i in. 2012). W przypadku stosowania odpadów poprodukcyjnych i kompostów na ich bazie jako dodatków podłożowych, wyzwanie stanowi często dostępność z punktu widzenia stałych dostaw, a także jakość i jednorodność tych materiałów pod względem chemicznym i fizycznym.

Obiecującym kierunkiem w tworzeniu nowych podłoży ogrodniczych jest wykorzystanie roślin uprawianych do tej pory główne na cele energetyczne. Rośliny te charakteryzują się szybkim przyrostem biomasy, mają stosunkowo niewielkie wymagania pokarmowe i agrotechniczne i są źródłem odnawialnym, dzięki czemu spełniają podstawowe kryteria zrównoważonego materiału do produkcji podłoży ogrodniczych. Przetestowano m. in. wierzbę, kukurydzę i miskanta (Altland 2010, Altland i Locke 2011, Clemmensen 2004, Kresten Jensen i in. 2000), jak również niewykorzystywane rolniczo rolniczo rośliny, jak proso rózgowe (Altland i Krause 2012, 2010, 2009a,b), czy lasecznica trzcinowata (Andreau-Rodriguez i in. 2013). Spośród tych gatunków, to miskant zyskuje na popularności, a powierzchnia jego uprawy zwiększa się zarówno w Stanach Zjednoczonych i Kanadzie, jak również Europie (Majtkowski 2007, Żurek 2008).

Miskant olbrzymi (*Miscanthus* × *giganteus* Greef et Deu), nazywany również trawą słoniową lub trzciną chińską, jest jednym z wielu gatunków należących do rodzaju *Miscanthus* – wysokich, wieloletnich traw, znanych przede wszystkim jako rośliny ozdobne i energetyczne. Jest on triploidalnym mieszańcem międzygatunkowym powstałym ze skrzyżowania diploidalnego miskanta chińskiego (*M. sinensis* Anderss.) oraz tetraploidalnego miskanta cukrowego ((*M. sacchariflorus* (Maxim.) Franch.) (Nishiwaki i in. 2011). W konsekwencji, miskant olbrzymi jako triploid jest całkowicie niepłodny, sterylny i nie zawiązuje nasion, rozmnażać go więc można jedynie wegetatywnie - poprzez podział kłączy i kępy macierzystej lub w kulturach *in vitro* (Clifton- Brown i in. 2001, Greef i Deuter 1993). Z punktu widzenia ogrodniczego użytkowania słomy z miskanta, jako ściółki bądź komponentu podłoży, sterylność tej rośliny energetycznej okazuje się być niezwykle korzystna– niweluje ona bowiem ryzyko zachwaszczenia uprawy jego siewkami.

Plon słomy z miskanta olbrzymiego wynosi średnio 10-20 t suchej masy na ha^{-1}, a w najbardziej korzystnych warunkach nawet do 30 t s.m. · ha^{-1}, co sprawia, że został on uznany za jedną z najlepiej plonujących roślin energetycznych klimatu umiarkowanego (Kahle i in. 2001, Heaton i in. 2010). Szybki przyrost biomasy tego gatunku związany jest głównie z jego przynależnością do grupy roślin szlaku C4, które charakteryzują się wydajniejszym procesem fotosyntezy w porównaniu do roślin szlaku C3. Dodatkowo częścią podziemną miskanta stanowią rizomy, które są nie tylko organem przetrwalnikowym, ale również źródłem składników pokarmowych w kolejnych latach uprawy. Pierwiastki, zwłaszcza azot, fosfor, potas i magnez, transportowane są ze źdźbeł i liści do rizomów pod koniec sezonu wegetacyjnego, a wiosną następuje ich mobilizacja i transport do nowych pędów. Sprawia to, że miskant olbrzymi jest częściowo niezależny od aktualnej zawartości pierwiastków w glebie i uzyskuje wysoki plon przy względnie niskich nakładach nawozowych (Beale i Long 1997). Biorąc pod uwagę termin zbioru miskanta, który wypada od jesieni aż do wiosny, oraz wyniki badań wskazujące na najwyższą zawartość azotu, fosforu, potasu i magnezu w części nadziemnej tuż przed osiągnięciem pełnej dojrzałości zbiorczej na cele energetyczne (Kahle i in. 2001), można wnioskować, że nieco wcześniejszy zbiór miskanta z przeznaczeniem podłoże ogrodnicze byłby korzystniejszy ze względu na wyższe zawartości tych pierwiastków w słomie, a tym samym możliwość redukcji nawożenia roślin uprawianych w podłożu na bazie słomy z miskanta. Rizomy miskanta wykazują również zdolność do akumulacji metali ciężkich, których to zawartości były wyższe w porównaniu do części nadziemnej (Jeżowska i in. 2006). Jest to zjawisko korzystne zarówno z energetycznego punktu widzenia, jako że metale ciężkie nie są uwalniane do atmosfery podczas spalania biomasy, jak również z ogrodniczego użytkowania słomy z miskanta, w którym to wypadku niższe zawartości metali ciężkich w słomie redukują ryzyko toksycznego wpływu tych pierwiastków na rośliny ściółkowane bądź uprawiane w podłożu z dodatkiem słomy z miskanta.

Kolejnym czynnikiem przemawiającym za podjęciem uprawy miskanta olbrzymiego jest jego długi okres plonowania, który wynosi nawet 30 lat. Ponadto już od 3-4 roku uprawy, plony miskanta wykazują stabilność zarówno pod względem wysokości produkcji biomasy, jak i jej jakości (Cerazy-Waliszewska i in. 2019). Miskant olbrzymi wykazuje również dość wysoką odporność na niskie temperatury, a także szkodniki i choroby (Jørgensen 2011), co również wpływa znacząco na zmniejszenie kosztów produkcji ze względu na ograniczenie stosowania zabiegów agrotechnicznych, a sam zbiór może być przeprowadzony przy użyciu standardowych maszyn rolniczych.

Jakość biomasy słomy z miskanta olbrzymiego jest porównywalna do biomasy drewna. Słomę z miskanta stanowią przede wszystkim ligniny i celuloza, i to właściwości fizyczne tych związków decydują o możliwościach jej wykorzystania. Najpowszechniejszym wykorzystaniem są cele energetyczne – w formie peletu do spalania bądź też do produkcji etanolu. Przetworzona słoma z miskanta olbrzymiego może być również wykorzystana w budownictwie do produkcji płyt czy materiałów kompozytowych, w przemyśle celulozowym do produkcji papieru i opakowań, w przemyśle samochodowym do produkcji opon, czy też w ogrodnictwie i rolnictwie jako ściółka dla zwierząt i roślin, a także jako podłoże ogrodnicze (Lewandowski 2005). Na dzień dzisiejszy czynnikiem limitującym szersze zastosowanie słomy z miskanta jest przede wszystkim brak wysoko rozwiniętych technologii, które zapewniałyby tanią i efektywną metodę przetwarzania tego lignocelulozowego materiału.

Zawartość celulozy, hemicelulozy i lignin w słomie miskanta, podobnie jak zawartość pierwiastków, zależą od wielu czynników, takich jak genotyp, rodzaj gleby czy termin zbioru. Przeciętna zawartość celulozy jest w zakresie 40-60%, hemiceluloza stanowi 20-40%, a ligniny od 10 do 30% masy całkowitej (Brosse i in. 2012). Z energetycznego punktu widzenia, słoma z miskanta ma większą wartość, gdy zawartość celulozy i hemicelulozy są wyższe, a lignin niższe. Wynika to bowiem z faktu, że celuloza i hemiceluloza rozkładają się do cukrów prostych, z których produkowane są następnie paliwa ciekłe, takie jak bioetanol, biobutanol czy biowodór (Jin i in. 2017). Z kolei rozpatrując wykorzystanie słomy z miskanta jako podłoża ogrodniczego, to wyższa zawartość lignin i niższa zawartość celulozy i hemicelulozy są bardziej korzystne. Ligniny zapewniają bowiem „szkielet" i stabilność podłoża, jako że rozkład lignin w warunkach tlenowych jest znikomy (Haug 1993); dodatkowo działają one hamująco na hydrolizę celulozy i hemicelulozy poprzez adsorpcję enzymów rozkładających te węglowodany. Zatem zawartość lignin wpływa zarówno bezpośrednio jak i pośrednio na rozkład celulozy i hemicelulozy, co przekłada się wprost na zmianę objętości podłoża w czasie trwania uprawy, a w konsekwencji również zmianę jego właściwości fizycznych (Dannehl i in. 2015).

Słoma z miskanta olbrzymiego, podobnie jak inne materiały lignocelulozowe, charakteryzuje się szerokim stosunkiem węgla do azotu wahającym się w zakresie 35-54 (Eiland i in. 2001). Przyjmuje się, że optymalnym stosunkiem C:N pozwalającym na rozkład materii organicznej jest 25, a im wyższa zawartość azotu i niższy stosunek węgla do azotu, tym szybciej przebiega proces rozkładu. Przy stosowaniu słomy jako podłoża niezbędne jest więc zastosowanie dodatkowej dawki azotu, która zaspokoi zapotrzebowanie mikroorganizmów na ten pierwiastek, jak również zapewni zawartość niezbędną dla wzrostu i rozwoju uprawianych roślin, a tym samym zredukuje ryzyko immobilizacji azotu (Jackson i in. 2009, Vandecasteele i in. 2016). Stosunek węgla do azotu w podłożach na bazie słomy z miskanta zmienia się w czasie uprawy (Bąbelewski i in. 2017) i zależy głównie od wahań zawartości azotu powodowanych przez aktywność mikrobiologiczną, pobór przez rośliny, wymywanie w trakcie nawadniania, a także wiązanie azotu cząsteczkowego bądź jego utlenianie. Z tego powodu istotne jest monitorowanie roślin pod kątem objawów niedoboru azotu i suplementacja w przypadku ich wystąpienia.

Rozdrobniona słoma charakteryzuje się wyższą pojemnością powietrzną, a także mniejszą pojemnością wodną i gęstością objętościową w porównaniu do torfu czy kory sosnowej. Jej dodatek powoduje więc istotne zmiany tych parametrów fizycznych, które w konsekwencji wpływają na wzrost i rozwój uprawianych roślin. Ponadto rośliny energetyczne, w tym miskant olbrzymi, zastosowane jako podłoża, charakteryzują się pH wyższym od przyjętego za optymalne przy produkcji ogrodniczej (Altland i Krause 2010, Altland i Locke 2011). Przeprowadzone dotychczas badania wykazują, że niezależnie od gatunku rośliny, której słoma była wykorzystana, podłoża bazujące na rozdrobnionej słomie wymagają dodatku innego komponentu (torf, kora, kompost), który ustabilizuje pH i właściwości fizyczne na poziomie zbliżonym do optymalnego (Altland i Krause 2010). Pomimo wyzwań związanych z właściwościami fizycznymi i chemicznymi, rozdrobniona słoma miskanta wykazała potencjał jako podłoże ogrodnicze. W uprawie ketmii bylinowej 'Luna Red' dodatek słomy z miskanta nie wpłynął na zawartość chlorofilu oraz miał nieistotny wpływ na zawartość składników pokarmowych w liściach. Ponadto, pomimo zmniejszania się suchej masy pędów wraz ze zwiększeniem dodatku słomy miskanta w podłożu, rośliny uprawiane przy dodatku 20-60% charakteryzowały się wysoką jakością pod względem wybarwienia i wzrostu w porównaniu do roślin uprawianych w komercyjnym podłożu z kory sosnowej, a wyraźna różnica była zaobserwowana dopiero przy 80% zawartości miskanta w podłożu (Altland i Locke 2011). Doświadczenia wykazały również przydatność rozdrobnionej słomy z miskanta olbrzymiego w procesie ukorzeniania sadzonek czterech gatunków krzewów ozdobnych: tawuły drobnokwiatowej, cisu pośredniego 'Hicksii', trzmieliny Fortune'a 'Emerald Gold' oraz irgi Dammera 'Major'. Procent ukorzenionych sadzonek tawuły, cisa oraz trzmieliny był statystycznie nieistotny pomiędzy podłożami, a w przypadku irgi 30, 50 i 70%-owy dodatek miskanta w podłożu przyczynił się do lepszego ukorzeniania w porównaniu do kontrolnego podłoża na bazie torfu (95% torf: 5% piasek). Masa pędów i korzeni irgi, tawuły i trzmieliny była ogólnie wyższa przy dodatku słomy na poziomie 30, 50 i 70%, a u sadzonek cisa najwyższą masę pędów i masę całkowitą odnotowano w podłożu zawierającym 95% słomy z miskanta z 5%-owym dodatkiem piasku (Bąbelewski i Pancerz 2016). Podłoże na bazie słomy z miskanta testowane było również w uprawie pomidora i ogórka (Kraska i in. 2018, Nguyen i in. 2019), co w efekcie pozwoliło na uzyskanie całkowitego plonu na poziomie porównywalnym do a roślin uprawianych w wełnie mineralnej.

Dostępna literatura potwierdza potencjał wykorzystania słomy z miskanta olbrzymiego jako podłoża ogrodniczego bądź dodatku do podłoży. Niewielka liczba gatunków testowanych w podłożach z miskanta nie daje jednak wyczerpujących odpowiedzi o wzroście i rozwoju roślin, a także zmianach w składzie chemicznym w zależności od ich wymagań pokarmowych i typu cyklu rozwojowego. Chcąc częściowo odpowiedzieć na te pytania, niniejsze doświadczenie zostało przeprowadzone na 6-ciu wybranych gatunkach roślin należących do dwóch grup rozwojowych: bylin (3 gatunki) oraz krzewów ozdobnych (3 gatunki), a w obrębie grupy rozwojowej gatunki zostały dobrane na podstawie ich wymagań pokarmowych (małe, średnie, wysokie), a były to kolejno: rudbekia błyskotliwa *Rudbeckia fulgida* ‘Goldsturm’, aster krzaczasty *Aster dumosus* 'Jenny', rozchodnik okazały *Sedum spectabile* ‘Stardust’, żywotnik *Thuja* ‘Smaragd’, tawuła gęstokwiatowa *Spiraea densiflora* Nutt. ex Torr. et A. Gray oraz hortensja krzewiasta *Hydrangea arborescens* ‘Annabelle’.

Celem badań była ocena przydatności świeżej, rozdrobnionej słomy z miskanta olbrzymiego w uprawie wybranych gatunków na podstawie parametrów biometrycznych roślin i stanu ich odżywienia oraz przeprowadzonych analiz chemicznych podłoży.

2. Materiały i metody

Doświadczenia przeprowadzono w Stacji Badawczo-Dydaktycznej w Psarach należącej do Uniwersytetu Przyrodniczego we Wrocławiu. Doświadczenia zakładano corocznie w połowie maja, począwszy od 2014 roku i powtórzono w 2015 i 2016. Pomiary roślin i analizy chemiczne wykonano dla bylin w pełni kwitnienia (połowa września), a dla krzewów w połowie października. Doświadczenie dwuczynnikowe 5x3 przeprowadzono metodą losowanych bloków, łącznie 15 kombinacji, każda składająca się z 24 roślin (8 roślin w 3 powtórzeniach).

2.1. Materiał roślinny i czynniki doświadczenia

Doświadczenie przeprowadzono na 6-ciu wybranych gatunkach roślin ozdobnych należących do dwóch grup rozwojowych: bylin (3 gatunki) oraz krzewów ozdobnych (3 gatunki), a w obrębie grupy rozwojowej gatunki zostały dobrane na podstawie ich wymagań pokarmowych (małe, średnie, wysokie), a były to kolejno: rudbekia błyskotliwa *Rudbeckia fulgida* ‘Goldsturm’, aster krzaczasty *Aster dumosus* 'Jenny', rozchodnik okazały *Sedum spectabile* ‘Stardust’, żywotnik *Thuja* ‘Smaragd’, tawuła gęstokwiatowa *Spiraea densiflora* Nutt. ex Torr. et A. Gray oraz hortensja krzewiasta *Hydrangea arborescens* ‘Annabelle’ (ryc. 1, 2 i 3).

Pierwszym czynnikiem były podłoża składające się z torfu i rozdrobnionej słomy z miskanta olbrzymiego w proporcjach:

1. 100% odkwaszonego torfu (kontrola),
2. 70% odkwaszonego torfu + 30 % słomy z miskanta,
3. 50% odkwaszonego torfu + 50% słomy z miskanta,
4. 30% odkwaszonego torfu + 70 % słomy z miskanta,
5. 100% słomy z miskanta.

Drugi czynnik stanowiły dwa typy nawozów (wolno działający Basacote 15-11-13 oraz łatwo rozpuszczalny w wodzie YaraMila 12-5-15) oraz sposoby ich zastosowania (mieszanie z podłożem/stosowanie pogłówne):

1. 3 $g \cdot dm^{-3}$ Basacote wymieszany z podłożem
2. 3 $g \cdot dm^{-3}$ Basacote wymieszany z podłożem z trzykrotnym nawożeniem pogłównym YaraMila w dawce 1 $g \cdot dm^{-3}$
3. 1 $g \cdot dm^{-3}$ YaraMila wymieszany z podłożem z trzykrotnym nawożeniem pogłównym YaraMila w dawce 1 $g \cdot dm^{-3}$

Sposób przygotowania słomy miskanta oraz podłoży zastosowanych w doświadczeniu został opisany na str. 30.

Ryc. 1. Tawuła gęstokwiatowa rosnąca w badanych podłożach na bazie miskanta

Ryc. 2. Krzewy hortensji krzewiastej ‘Annabelle’ rosnąca w badanych podłożach na bazie miskanta

Ryc. 3. Rośliny astra krzaczastego ‘Jenny’ rosnące w badanych podłożach na bazie miskanta

Pomiary biometryczne roślin

Badane cechy biometryczne zależały od morfologii gatunków i zostały opisane odpowiednio: dla hortensji i rozchodnika str. 31-32, dla rudbekii i żywotnika str. 38-39, a dla tawuły i astra str. 67-68.

2.2. Analizy liści oraz podłoży

W celu przeprowadzenia analiz liści, z każdej kombinacji dla każdego z testowanych gatunków pobrano 20-25 liści. Analizy obejmowały zawartość chlorofili, jasność i tony barw (z wyjątkiem żywotnika) oraz zawartość wybranych pierwiastków. Opis analiz chemicznych znajduje się na str. 32.

W celu przeprowadzenia analiz podłoży, pobrano łącznie i ujednolicono 500ml każdego z podłoży w uprawie każdego z testowanych gatunków z 8 losowo wybranych doniczek. W podłożach oznaczono pH, EC oraz zawartość wybranych pierwiastków. Opis analiz podłoży znajduje się na str. 32.

2.3. Analiza statystyczna

Analizy statystyczne zebranych pomiarów i wyników analiz przeprowadzono za pomocą pakietu statystycznego Statistica 13.3.721.0. W celu zbadania istotności różnic pomiędzy poszczególnymi stanowiskami badawczymi przeprowadzono jednoczynnikową analizę wariancji ANOVA z testowaniem istotności różnic testem Najmniejszej Istotnej Różnicy (NIR) oraz testem Fishera, wyznaczając grupy jednorodne skupiające wartości nie różniące się na poziomie istotności $\alpha=0{,}05$.

3. Wyniki i dyskusja

3.1. Assessment of Fresh Miscanthus Straw as Growing Media Amendment in Nursery Production of Sedum spectabile ‘Stardust’ and Hydrangea arborescens ‘Annabelle’. Pancerz, M., Czaplicka, M. and Bąbelewski, P., 2023. *Plants*, *12*(8), p.1639

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Assessment of Fresh Miscanthus Straw as Growing Media Amendment in Nursery Production of *Sedum spectabile* 'Stardust' and *Hydrangea arborescens* 'Annabelle'

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Abstract: The aim of this research was to assess the influence of fresh miscanthus straw shreds as a component of growing media in nursery production of perennial *Sedum spectabile* 'Stardust' and woody shrub *Hydrangea arborescens* 'Annabelle'. A total of five substrate mixes composed of peatmoss and miscanthus straw were used: 100%P, 70%P:30%M, 50%P:50%M, 70%P:30%M, 100%M. Each substrate was subjected to three fertilizer treatments: Basacote, Basacote + YaraMila, and YaraMila. The growth response of both tested species was very similar. In general, plants performed best in 100%P, and the quality decreased with increasing miscanthus straw amendment; however, differences in height and dry weight at the level of ~9% suggest that *Sedum* plants obtained market value with up to 50% miscanthus amendment and *Hydrangea* plants with up to 30% miscanthus mixed in media. The most favorable effect on the tested parameters was a combination of Basacote + YaraMila, which delivered more soluble salts, and in higher rates than Basacote and YaraMila used separately. Decrease in EC and nutrients in the substrate with increase in miscanthus straw amendment suggest that uniform irrigation among all the treatments contributed to nutrients leaching from miscanthus media due to its lower water holding capacity.

Keywords: soilless substrates; peatmoss; ornamental plants; fertilization

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1. Introduction

Greenhouse and nursery production depends on peatmoss as the basic growing medium. Increasing plant production requires progressively greater use of soilless substrates in the horticultural industry. Block et al. [1] predicts that global demand for soilless substrates will double in the next 20 years. Despite the many advantages of peatmoss, environmental concerns related to peat harvesting [2,3] have led to the view of peatmoss as an unrenewable and unsustainable material [4] and, furthermore, to the establishment of legal protection of wetlands in some areas of the world [5]. Reduced availability and uncertainty regarding peatmoss in both the near and distant future have opened investigation of materials that could substitute for peat in soilless substrates.

The search for new materials suitable for container production is occurring in two ways: finding components that reduce the quantity of peatmoss used in the mix, or completely replacing peatmoss. Two raw materials that were profitably and successfully used as peatmoss substitutes are pine bark and coir, used separately or in mixes [6–9]. Pine bark has been used as a soilless medium alongside peatmoss for several decades [10–13] and is being subsequently replaced by wood materials [14–17]. However, changes in the forest industry are causing a decrease in wood derived materials available for horticultural production and are modifying the dynamics relating to woody materials obtainable for soilless media. Coir, as a waste material from coconut husks, was first used in tropical countries as a locally available material for soilless substrates [18]. With the development of processing and compressing it into bricks or bales, allowing for easier transportation [19,20], it became a peat replacement in container production in other areas of the world [21–23]. However, ecological concerns related to the carbon footprint associated with coir transportation, as well as the erratic quality of the raw material, very often showing high salinity and other contaminations affecting plant growth [22,24], are slowly sidetracking this material when considering it as peatmoss substitute.

As highlighted by [25], to achieve an environmentally sustainable substrate, raw materials have to be selected with regard to their performance under practical conditions, economical aspects, including equal or better characteristics than commercially available growing media, and ecological aspects that consider the sustainability of any given material. Among renewable resources that should be considered as raw materials for soilless substrates, energy crops come into play due to their fast and high biomass production that has relatively low cultivation requirements compared to other crops. Miscanthus (*Miscanthus × giganteus*), a tall hybrid C4 grass genotype with proven utility as a biomass crop, was described by Heaton et al. [26] as one of the most productive land plants in temperate climates. This statement was confirmed by Dohleman and Long [27], who showed in their studies that miscanthus was more productive and efficient than maize and other C4 cols resistant biomass crops. Moreover, miscanthus plants, after a few years of establishment, are characterized by stable biomass and adequate biomass quantity [28]. This led several researchers to conduct trials into the use of miscanthus straw as potting medium [29–34].

As there are few studies on the use of miscanthus straw in ornamental plant production, the authors decided to assess plant performance in miscanthus straw amended media on two selected ornamental species: perennial *Sedum spectabile* 'Stardust' and woody shrub *Hydrangea arborescens* 'Annabelle', followed by the chemical analysis of leaf tissues of the tested species and substrate analyses.

2. Results and Discussion

2.1. Plant Performance Measurements

2.1.1. Height, Diameter and Shoot Growth

Both *Sedum* (Table 1) and *Hydrangea* (Table 2) were the tallest with the widest diameter when grown in 100% peatmoss, and the shortest with the smallest diameter when grown in miscanthus straw. For *Hydrangea,* the difference in height compared with miscanthus was about 50% less when compared to the peatmoss control, and for *Sedum* a difference of around 50% was noticed in diameter. In general, both species decreased in height and diameter with the increase of miscanthus straw in the media, which suggests that water availability for plants decreased along with increasing miscanthus amendment in the substrate. Similar results were obtained by Tsakaldimi and Ganatas [35] growing seedlings of three native tree species, where the use of kenaf in the substrate resulted in significant reduction in seedling dimensions, height, and diameter, with an increased proportion of rice hulls. Starr et al. [36], growing seedlings of bald cypress, Chinese pistachio and silver maple in substrates with the amendment of eastern redcedar, noticed that less growth occurred when plants were grown in 80% amendment of eastern redcedar in media, while *Sedum* and *Hydrangea* mixes containing 70% and 100% seemed to cause the biggest decrease the height and diameter of plants. *Sedum* and *Hydrangea* were the tallest and with a larger diameter when fertilized with Basacote + YaraMila. These results indicate that, for plants with high nutritional requirements, using controlled released fertilizer together with easy soluble fertilizer can be the most beneficial practice. Both *Sedum* and *Hydrangea* were the shortest and with the smallest diameter in miscanthus straw with Basacote fertilizer. This is most likely linked to the lower water holding capacity of miscanthus straw in comparison to peatmoss media, resulting in excessive leaching of nutrients, or to not enough provision of saturation to release nutrients from the coated slow release fertilizer. The highest *Sedum* plants that were the largest in diameter were found in peatmoss with Basacote + YaraMila fertilizer, and foe *Hydrangea* in 100% peatmoss and 70% peatmoss media with YaraMila. In terms of main shoot number and length, *Hydrangea* expressed similar tendencies to those for height and diameter, having the greatest number of the longest shoots in 100%P substrate and in Basacote + YaraMila fertilizer (Table 2). As noticed by Roosta and Afsharipoor [37], vigorous vegetative growth observed in peat is most likely due to higher nutrient uptake and possibly the high water content.

Table 1. Selected biometric features of *Sedum spectabile* 'Stardust' grown in containers with five different substrates.

Substrate (A)	Fertilization (B)			
	Basacote® Plus 6M 16-8-12(+2 + TE) 2 doses	**Basacote + YaraMila**	**YaraMila 12N(5N-NO_3+7N-NH_4) +11P_2O_5+18K_2O +2.7MgO +20SO_3 +0.015B+0.2Fe +0.02Mn +0.02Zn**	**Mean A**
	Height (cm)			
100% P	30.7 e	37.6 a	34.4 bc	34.2 a
70%P + 30%M	32.9 d	35.5 b	28.9 f	32.4 b
50%P + 50%M	30.7 e	33.8 cd	26.3 g	30.3 c
30%P + 70%M	27.3 g	39.9 ef	26.2 gh	27.8 d
100%M	23.0 i	28.7 f	24.9 h	25.5 e
Mean B	28.9 b (32.9–23.0)	33.1 a (39.9–28.7)	28.1 c (34.4–24.9)	
	Diameter (cm)			
100% P	25.9 c	29.4 a	27.9 b	27.7 a
70%P + 30%M	24.2 e	26.4 c	21.2 f	23.9 b
50%P + 50%M	21.2 fg	25.0 d	15.1 j	20.4 c
30%P + 70%M	17.3 i	20.5 gh	14.7 j	17.5 d
100%M	13.0 k	19.9 h	15.0 j	16.0 e
Mean B	20.3 b (25.9–13.0)	24.24 a (29.4–19.9)	18.8 c (27.9–14.7)	

(A) composed of various combinations of peatmoss (P) and miscanthus straw (M), along with one of three fertilizers (B), including either Basacote (15-11-13) or water soluble YaraMila Complex (12-5-15), either alone or in combination. Different lower case letters within mean A, mean B and A × B interaction indicate statistically significant differences at the significance level of ($p < 0.05$) by Fisher's test.

Table 2. Selected biometric features of *Hydrangea arborescence* 'Annabelle' grown in containers with five different substrates.

Substrate (A)	Fertilization (B)			
	Basacote	**Basacote + YaraMila**	**YaraMila**	**Mean A**
	Height (cm)			
100% P	43.5 c	47.1 b	51.2 a	47.3 a
70%P + 30%M	37.0 e	49.7 a	40.8 d	42.5 b
50%P + 50%M	34.6 f	44.2 c	30.8 g	36.6 c
30%P + 70%M	30.9 g	29.1 h	25.5 h	28.5 d
100%M	20.7 j	21.4 j	23.2 i	21.8 e
Mean B	33.3 c (43.5–20.7)	38.3 a (49.7–21.4)	34.3 b (51.2–23.2)	

Table 2. *Cont.*

Substrate (A)	Fertilization (B)			
	Basacote	Basacote + YaraMila	YaraMila	Mean A
	Height (cm)			
	Diameter (cm)			
100% P	34.2 c	38.1 b	40.7 a	37.7 a
70%P + 30%M	30.8 d	40.1 a	30.7 d	33.9 b
50%P + 50%M	34.8 c	40.7 a	26.6 f	33.7 b
30%P + 70%M	26.2 f	28.2 e	27.5 ef	27.3 c
100%M	16.2 i	19.9 h	23.5 g	19.9 d
Mean B	28.3 c (34.8–16.2)	33.4 a (40.7–19.9)	29.8 b (40.7–23.5)	
	Main shoot number			
100% P	3.8 cd	4.3 b	3.9 c	3.9 a
70%P + 30%M	3.6 d	3.1 e	2.4 g	3.0 c
50%P + 50%M	2.8 f	4.9 a	2.4 g	3.3 b
30%P + 70%M	2.4 g	2.0 h	3.2 e	2.5 d
100%M	1.7 i	2.4 g	1.5 i	1.8 e
Mean B	2.8 b (3.8–1.7)	3.3 a (4.3–2.0)	2.7 c (3.9–1.5)	
	Main shoot length (cm)			
100% P	32.5 d	36.8 b	41.6 a	36.9 a
70%P + 30%M	29.5 ef	41.3 a	34.5 cd	34.8 b
50%P + 50%M	28.5 f	34.6 c	30.7 e	31.3 c
30%P + 70%M	29.0 ef	25.7 g	25.6 g	26.8 d
100%M	16.0 i	18.8 h	19.6 h	18.1 e
Mean B	27.1 c (32.5–16.0)	31.5 a (41.3–18.8)	30.2 b (41.6–19.6)	

(A) composed of various combinations of peatmoss (P) and miscanthus straw (M), along with one of three fertilizers (B), including either Basacote (15-11-13) or water soluble YaraMila Complex (12-5-15), either alone or in combination. Different lower case letters within mean A, mean B and A × B interaction indicate statistically significant differences at the significance level of ($p < 0.05$) by Fisher's test.

2.1.2. Flowering

Sedum produced the greatest inflorescence number (Table 3), and was also the tallest, in peatmoss substrate, and was the least, shortest, and smallest in diameter in 100% miscanthus. This suggests that nutrients, especially the phosphorus responsible for flowering, was leaching in much greater amounts from miscanthus based media, negatively affecting the generative stage of plants. Harris et al. [38] observed that petunia at the end of the production phase had the lowest number of flowers in peat:wood and peat:fiber media, in comparison to peat:coir mixes. Awang et al. [39] also noted a negative effect of media containing kenaf core fiber on flower size of *Celosia cristata*. For *Sedum*, the most favorable for flower features was fertilization with Basacote + YaraMila, delivering more soluble salts from the two different types of fertilizer. Among the substrate x fertilizer interactions, the least favorable was miscanthus substrate with Basacote, which can be affected by the low water holding capacity of miscanthus straw that did not allow Basacote, as a coated fertilizer, to release nutrients to the medium. As highlighted by Niemiera and Leda [40], N leaching losses in liquid fertilizer are higher than in controlled released fertilizer; however, depending on the application rate, relative N losses from CRF can be significant and reach 12–23%. These data can suggest that phosphorus, which has high mobility in soilless media and is prone to leaching, could also be subject to similar tendencies as with nitrogen.

Table 3. Flowering of *Sedum spectabile* 'Stardust' grown in containers with five different substrates.

Substrate (A)	Fertilization (B)			
	Basacote	Basacote + YaraMila	YaraMila	Mean A
	Inflorescence Number			
100% P	6.7 ab	6.6 c	6.8 ab	6.7 a
70%P + 30%M	4.9 gh	6.7 ab	6.1 e	5.9 c
50%P + 50%M	6.0 de	7.0 a	5.1 fg	6.1 b
30%P + 70%M	4.1 i	5.2 f	4.7 h	4.7 d
100%M	4.0 i	5.2 f	5.1 fg	4.7 d
Mean B	5.2 c (6.7–4.0)	6.09 a (7.0–5.2)	5.6 b (6.8–4.7)	

(A) composed of various combinations of peatmoss (P) and miscanthus straw (M), along with one of three fertilizers (B), including either Basacote (15-11-13) or water soluble YaraMila Complex (12-5-15), either alone or in combination. Different lower case letters within mean A, mean B and A × B interaction indicate statistically significant differences at the significance level of ($p < 0.05$) by Fisher's test.

2.1.3. Leaf Measurements

Both *Sedum* (Table 4) and *Hydrangea* (Table 5) showed similar leaf response to growing media mixes: leaf number, length, width and leaf blade area of both species tended to be the greatest in plants grown in peatmoss and the lowest in those cultivated in miscanthus straw. Similar results were observed by Bassan at al. [41] in leaf number and area of tomato transplants, negatively affected by increasing rates of rice hull in the media. As both miscanthus and rice hulls have lower water holding capacity than peatmoss, these results can be affected by water availability. As Saberi et al. [42] noticed in forage sorghum, leaf area of plants was reduced in response to decreasing water availability. *Hydrangea* produced the lowest number of the smallest leaves in Basacote, and Prince et al. [43] similarly noticed that one time application of a standard rate of controlled released fertilizer had a negative effect on leaf area of potted chrysanthemum. *Sedum* had the lowest number of the smallest leaves in YaraMila. Both species had the lowest number of the smallest leaves when grown in miscanthus with the use of Basacote. For *Sedum,* the most favorable for leaf growth and development were media containing 100%, 70% and 50% peatmoss, with the use of Basacote + YaraMila, while for *Hydrangea,* peatmoss with YaraMila fertilization was best.

2.1.4. Dry Biomass

Sedum accumulated the highest dry weight of roots in peatmoss media, and the highest shoot dry weight in 70% peatmoss (Table 6). Gomez and Robbins [44] found that shoot dry weight of spirea was significantly greater with up to 40% of rice hulls in the media, and decreased as the percentage of rice hulls increased in the blends. *Hydrangea* had the highest fresh weights of shoot part and roots in 70% peatmoss, but the highest dry weight for both was in 100% peatmoss (Table 7). Tsakaldimi and Ganatas [35], growing seedlings of three native tree species, observed that the use of kenaf decreased seedling biomass, what confirms the reaction of *Sedum,* which produced the lowest fresh and dry weight of shoot parts and roots when grown in 100% miscanthus. In general, the biomass of both species decreased with the increase of miscanthus straw in the media. Similarly, Webber et al. [45] found that shoot and root dry weights of *Vinca minor* decreased as the percentage of kenaf increased. Frangi et al. [46] obtained similar results, where shoot dry weight of cherry laurel was negatively influenced when the quantities of *Arundo donax* and *Miscanthus sinensis* fiber increased in the growing medium. In both species, the highest dry weights were noticed in Basacote + YaraMila fertilizer, and plants grown only in YaraMila were characterized by the lowest fresh and dry weights of shoot parts and roots. *Hydrangea* showed a highly unified response on substrate × fertilizer treatment and had the highest dry weights in 70% peatmoss with Basacote + YaraMila and the lowest in miscanthus fertilized with YaraMila.

Table 4. Selected leaf features of *Sedum spectabile* 'Stardust' grown in containers with five different substrates.

Substrate (A)	Fertilization (B)			
	Basacote	Basacote + YaraMila	YaraMila	Mean A
	Leaves Number			
100% P	84.8 a	70.2 b	50.4 c	68.5 a
70%P + 30%M	40.6 e	40.4 e	43.2 d	41.4 b
50%P + 50%M	39.5 e	41.1 e	26.3 g	35.6 c
30%P + 70%M	27.8 g	30.0 f	24.4 h	27.4 d
100%M	20.5 j	23.3 hi	21.7 ij	21.8 e
Mean B	42.6 a	41.0 b	33.2 c	
	Leaf blade area (cm^3)			
100% P	14.29 e	19.56 a	17.61 b	17.15 a
70%P + 30%M	17.04 c	17.26 bc	16.13 d	16.81 b
50%P + 50%M	14.23 e	19.38 a	9.33 h	14.31 c
30%P + 70%M	11.22 g	15.83 d	9.62 h	12.22 d
100%M	6.52 j	12.84 f	8.11 i	9.16 e
Mean B	12.66 b	16.98 a	12.16 c	

(A) composed of various combinations of peatmoss (P) and miscanthus straw (M), along with one of three fertilizers (B), including either Basacote (15-11-13) or water soluble YaraMila Complex (12-5-15), either alone or in combination. Different lower case letters within mean A, mean B and A × B interaction indicate statistically significant differences at the significance level of ($p < 0.05$) by Fisher's test.

Table 5. Selected leaf features of *Hydrangea arborescence* 'Annabelle' grown in containers with five different substrates.

Substrate (A)	Fertilization (B)			
	Basacote	Basacote + YaraMila	YaraMila	Mean A
	Leaves Number (Total)			
100% P	59.8 d	68.8 c	71.3 b	66.6 a
70%P + 30%M	60.1 d	55.7 e	50.4 f	55.4 b
50%P + 50%M	44.6 h	85.1 a	34.5 j	54.7 b
30%P + 70%M	29.9 k	36.7 i	23.8 m	30.2 d
100%M	34.1 j	26.0 l	46.9 g	35.7 c
Mean B	45.7 b	54.5 a	45.4 b	
	Leaf blade area (cm^3)			
100% P	50.69 e	63.73 c	84.50 a	66.31 a
70%P + 30%M	63.05 c	69.39 b	58.08 d	63.51 a
50%P + 50%M	39.40	53.98 de	47.33 ef	46.90 b
30%P + 70%M	45.80 f	43.35 f	41.67 f	43.61 b
100%M	15.82 h	27.64 g	26.56 g	23.34 c
Mean B	42.95 b	32.79 c	51.63 a	

(A) composed of various combinations of peatmoss (P) and miscanthus straw (M), along with one of three fertilizers (B), including either Basacote (15-11-13) or water soluble YaraMila Complex (12-5-15), either alone or in combination. Different lower case letters within mean A, mean B and A × B interaction indicate statistically significant differences at the significance level of ($p < 0.05$) by Fisher's test.

Table 6. Fresh and dry weight of *Sedum spectabile* 'Stardust' grown in containers with five different substrates.

Substrate (A)	Fertilization (B)			
	Basacote	Basacote + YaraMila	YaraMila	Mean A
	Shoot Fresh Weight (g)			
	Shoot dry weight (g)			
100% P	115.22 e	166.37 c	137.49 d	139.69 b
70%P + 30%M	132.91 d	200.51 a	102.32 f	145.25a
50%P + 50%M	131.51 d	193.70 b	54.30 h	126.50 c
30%P + 70%M	99.32 f	113.70 e	73.19 g	95.40 d
100%M	45.18 i	118.53 e	75.65 g	79.79 e
Mean B	104.83 b	158.56 a	88.59 c	
	Root dry weight (g)			
100% P	30.26 b	28.20 c	23.44 fg	27.30 a
70%P + 30%M	25.70 e	24.04 f	19.91 i	23.22 c
50%P + 50%M	27.35 d	33.63 a	17.59 j	26.19 b
30%P + 70%M	22.57 h	24.06 f	17.33 j	21.32 d
100%M	14.36 k	22.83 gh	16.96 j	18.05 e
Mean B	24.05 b	26.55 a	19.05 c	

(A) composed of various combinations of peatmoss (P) and miscanthus straw (M), along with one of three fertilizers (B), including either Basacote (15-11-13) or water soluble YaraMila Complex (12-5-15), either alone or in combination. Different lower case letters within mean A, mean B and A × B interaction indicate statistically significant differences at the significance level of ($p < 0.05$) by Fisher's test.

Table 7. Fresh and dry weight of *Hydrangea arborescence* 'Annabelle' grown in containers with five different substrates.

Substrate (A)	Fertilization (B)			
	Basacote	Basacote + YaraMila	YaraMila	Mean A
	Shoot Fresh Weight (g)			
	Shoot dry weight (g)			
100% P	45.07 b	47.80 a	34.11 e	42.32 a
70%P + 30%M	34.80 e	40.20 d	23.51 h	32.83 c
50%P + 50%M	42.20 c	42.80 c	26.35 g	37.11 b
30%P + 70%M	31.02 f	16.11 k	19.17 i	22.10 d
100%M	17.58 j	8.51 l	5.40 m	10.50 e
Mean B	34.13 a	31.09 b	21.71 c	
	Root dry weight (g)			
100% P	13.60 b	12.97 c	11.13 d	12.23 a
70%P + 30%M	11.20 d	14.10 a	8.15 h	11.15 b
50%P + 50%M	14.08 a	14.04 a	9.00 g	12.37 a
30%P + 70%M	10.32 e	13.90 ab	5.04 i	9.75 c
100%M	8.02 h	9.86 f	4.09 j	7.32 d
Mean B	11.44 b	12.77 a	7.48 c	

(A) composed of various combinations of peatmoss (P) and miscanthus straw (M), along with one of three fertilizers (B), including either Basacote (15-11-13) or water soluble YaraMila Complex (12-5-15), either alone or in combination. Different lower case letters within mean A, mean B and A × B interaction indicate statistically significant differences at the significance level of ($p < 0.05$) by Fisher's test.

2.2. Analyses of Leaves

Higher concentration of chlorophylls in *Sedum* (Table 8) were in general found in media containing 70% and 100% miscanthus, while in *Hydrangea* (Table 9) all chlorophylls were highest in peatmoss, which supports the color reading of the leaves when regarding the darkest leaves with the bluest tone in this medium (data not shown).

Chlorophyll contents in *Hydrangea* and *Sedum* were the highest in Basacote, with YaraMila species having the darkest leaves with the greenest tone and the bluest tone in this fertilization treatment.

The lowest chlorophyll content in *Sedum* was in YaraMila fertilization, while for Hydrangea this was in *Basacote*. For *Sedum*, there was no clear pattern of chlorophyll concentrations within substrate × fertilizer treatment. On the other hand, in *Hydrangea*, all tested chlorophylls were the highest in peatmoss with Basacote + YaraMila, and lowest, as for leaf color readings, in miscanthus substrate with YaraMila fertilizer. Contradictory findings were shown in strawberry cultivation in coir, peat, reed canary grass and a mix of peat with reed canary grass, where strawberry leaf chlorophyll content did not differ between the treatments [47].

Foliar nutrients did not show any tendencies and their highest and lowest values were spread among substrate types within the species, and there were no consistent tendencies when comparing nutritional status of leaves of both *Sedum* (Table 10) and *Hydrangea* (Table 11). A similar situation occurred in fertilizer and in substrate × fertilizer treatments. As suggested by Mustafa et al. [48], different media amendments can display different extractability and, due to many interactions between media components, cause discrepancies between substrate and foliar nutrient levels.

Table 8. Chlorophyll contents (mg/g) in leaves of *Sedum spectabile* 'Stardust' grown in containers with five different substrates.

Substrate (A)	**Fertilization (B)**			
	Basacote	**Basacote + YaraMila**	**YaraMila**	**Mean A**
		Chlorophyll a		
100% P	0.174 d	0.220 b	0.164 e	0.186 b
70%P + 30%M	0.112 g	0.133 f	0.080 h	0.109 e
50%P + 50%M	0.110 g	0.169 de	0.104 g	0.128 d
30%P + 70%M	0.132 f	0.194 c	0.173 de	0.166 c
100%M	0.531 a	0.167 de	0.088 h	0.262 a
Mean B	0.212 a	0.176 b	0.122 c	
		Chlorophyll b		
100% P	0.148 a	0.112 c	0.107 cd	0.122 a
70%P + 30%M	0.087 fg	0.090 f	0.070 i	0.082 b
50%P + 50%M	0.06 4i	0.101 e	0.083 g	0.083 b
30%P + 70%M	0.102 de	0.129 b	0.131 b	0.121 a
100%M	0.058 j	0.110 c	0.076 h	0.081 b
Mean B	0.092 b	0.109 a	0.093 b	
		Total chlorophyll		
100% P	0.322 b	0.331 b	0.271 d	0.308 b
70%P + 30%M	0.200 f	0.224 e	0.150 h	0.191 e
50%P + 50%M	0.174 g	0.271 d	0.187 f	0.210 d
30%P + 70%M	0.233 e	0.324 b	0.304 c	0.287 c
100%M	0.589 a	0.277 d	0.165 g	0.343 a
Mean B	0.304 a	0.285 b	0.215 c	

(A) composed of various combination of peatmoss (P) and miscanthus straw (M), along with one of three fertilizers (B) including either Basacote (15-11-13) or water soluble YaraMila Complex (12-5-15) either alone or in combination. Different lower case letters within mean A, mean B and A × B interaction indicate statistically significant differences at the significance level ($p < 0.05$) by Fisher's test.

Table 9. Chlorophyll contents (mg/g) in leaves of *Hydrangea arborescence* 'Annabelle' grown in containers with five different substrates.

Substrate (A)	Fertilization (B)			
	Basacote	**Basacote + YaraMila**	**YaraMila**	**Mean A**
		Chlorophyll a		
100% P	0.500 h	0.936 a	0.907 b	0.781 a
70%P + 30%M	0.438 i	0.604 g	0.502 h	0.515 d
50%P + 50%M	0.619 g	0.723 e	0.690 f	0.678 c
30%P + 70%M	0.496 h	0.806 d	0.872 c	0.725 b
100%M	0.518 h	0.623 g	0.377 j	0.506 d
Mean B	0.514 c	0.739 a	0.670 b	
		Chlorophyll b		
100% P	0.359 f	0.504 a	0.469 b	0.444 a
70%P + 30%M	0.206 l	0.311 h	0.272 j	0.263 d
50%P + 50%M	0.304h i	0.388 e	0.355 f	0.349 c
30%P + 70%M	0.297 i	0.456 c	0.443 d	0.399 b
100%M	0.249 k	0.334 g	0.205 l	0.263 d
Mean B	0.283 c	0.399 a	0.349 b	
		Total chlorophyll		
100% P	0.859 i	1.440 a	1.376 b	1.225 a
70%P + 30%M	0.644 k	0.915 h	0.774 j	0.778 d
50%P + 50%M	0.923 h	1.111 e	1.045 f	1.027 c
30%P + 70%M	0.793 j	1.263 d	1.315 c	1.124 b
100%M	0.767 j	0.958 g	0.582 l	0.769 d
Mean B	0.797 c	1.137 a	1.019 b	

(A) composed of various combinations of peatmoss (P) and miscanthus straw (M), along with one of three fertilizers (B), including either Basacote (15-11-13) or water soluble YaraMila Complex (12-5-15), either alone or in combination. Different lower case letters within mean A, mean B and A × B interaction indicate statistically significant differences at the significance level of ($p < 0.05$) by Fisher's test.

Table 10. Foliar nutrient contents (mg/g) in *Sedum spectabile* 'Stardust' grown in containers with five different substrates.

Substrate (A)	Fertilization (B)			
	Basacote	**Basacote + YaraMila**	**YaraMila**	**Mean A**
		NO_{3-}		
100% P	21.7 cd	29.3 a	22.3 c	24.4 a
70%P + 30%M	20.3 def	18.7 f	20.7 cde	19.9 c
50%P + 50%M	24.3 b	20.3 def	19.7 ef	21.4 b
30%P + 70%M	19.3 ef	16.3 g	16.7 g	17.4 d
100%M	16.3 g	137 h	14.3 h	14.8 e
Mean B	20.4 a	19.7 a	18.7 b	
		P		
100% P	182 i	247 f	372 a	267 a
70%P + 30%M	198 h	227 g	300 c	242 d
50%P + 50%M	277 e	287 d	203 h	255 b
30%P + 70%M	197 h	347 b	197 h	247 c
100%M	201 h	226 g	275 e	234 e
Mean B	211 b	267 a	269 a	

Table 10. *Cont.*

Substrate (A)	Fertilization (B)			
	Basacote	Basacote + YaraMila	YaraMila	Mean A
		NO_3^-		
		K		
100% P	1817 ef	1467 h	2017 c	1767 c
70%P + 30%M	1617 g	1792 f	2642 a	2016 a
50%P + 50%M	1867 de	1900 d	2183 b	1983 b
30%P + 70%M	1142 i	1908 d	1933 d	1661 d
100%M	1192 i	1483 h	1492 h	1389 e
Mean B	1527 c	1710 b	2053 a	
		Ca		
100% P	6208 b	4067 i	5683 d	5319 c
70%P + 30%M	6117 b	4933 f	5933 c	5661 b
50%P + 50%M	7792 a	5108 e	4758 g	5886 a
30%P + 70%M	5742 d	3942 j	4367 h	4683 d
100%M	4767 g	3442 l	3642 k	3950 e
Mean B	6125 a	4298 c	4877 b	
		Mg		
100% P	146 e	204 a	199 a	183 a
70%P + 30%M	153 e	180 b	171 c	168 c
50%P + 50%M	201 a	198 a	161 d	187 a
30%P + 70%M	150 e	150 e	128 f	143 d
100%M	145 e	205 a	168 cd	173 b
Mean B	159 c	187 a	166 b	

(A) composed of various combinations of peatmoss (P) and miscanthus straw (M), along with one of three fertilizers (B), including either Basacote (15-11-13) or water soluble YaraMila Complex (12-5-15), either alone or in combination. Different lower case letters within mean A, mean B and A × B interaction indicate statistically significant differences at the significance level of ($p < 0.05$) by Fisher's test.

Table 11. Foliar nutrient contents (mg/g) in *Hydrangea arborescence* 'Annabelle' grown in containers with five different substrates.

Substrate (A)	Fertilization (B)			
	Basacote	Basacote + YaraMila	YaraMila	Mean A
		NO_3^-		
100% P	14.1 a	13.1 c	12.9 c	13.4 a
70%P + 30%M	13.5 b	11.3 e	12.1 d	12.3 b
50%P + 50%M	13.0 c	10.9 f	10.8 f	11.6 c
30%P + 70%M	11.3 e	10.6 f	10.6 f	10.8 d
100%M	10.6 f	10.6 f	10.8 f	10.6 e
Mean B	12.5 a	11.3 b	11.4 b	
		P		
100% P	142 j	344 a	220 f	235 b
70%P + 30%M	179 g	167 h	231 e	192 d
50%P + 50%M	156 i	230 e	180 g	189 d
30%P + 70%M	288 c	131 k	214 f	211 c
100%M	305 b	274 d	301 b	293 a
Mean B	214 b	229 a	229 a	

Table 11. *Cont.*

Substrate (A)	Fertilization (B)			
	Basacote	Basacote + YaraMila	YaraMila	Mean A
		NO_{3-}		
		K		
100% P	83 gh	157 c	103 e	114 b
70%P + 30%M	87 fg	173 b	83 gh	114 b
50%P + 50%M	120 d	247 a	87 fg	151 a
30%P + 70%M	87 fg	127 d	73 hi	96 c
100%M	63 ij	97 ef	53 j	71 d
Mean B	88 b	160 a	80 c	
		Ca		
100% P	1550 de	1337 gh	1570 cd	1486 b
70%P + 30%M	1350 fgh	1397 f	1300 h	1349 c
50%P + 50%M	2160 a	1607 c	1983 b	1917 a
30%P + 70%M	1503 e	1383 fg	1587 cd	1491 b
100%M	593 i	547 i	583 i	574 d
Mean B	1431 a	1254 c	1405 b	
		Mg		
100% P	282 d	199 j	227 h	236 d
70%P + 30%M	290 d	395 a	283 d	322 a
50%P + 50%M	214 i	340 b	252 ef	268 b
30%P + 70%M	247 efg	242 fg	253 e	247 c
100%M	305 c	254 e	239 g	266 b
Mean B	268 b	286 a	251 c	

(A) composed of various combinations of peatmoss (P) and miscanthus straw (M), along with one of three fertilizers (B), including either Basacote (15-11-13) or water soluble YaraMila Complex (12-5-15), either alone or in combination. Different lower case letters within mean A, mean B and A × B interaction indicate statistically significant differences at the significance level of ($p < 0.05$) by Fisher's test.

2.3. Substrate Analyses

In substrates of both *Sedum* (Table 12) and *Hydrangea* (Table 13), pH and EC were the highest in peatmoss media, and the lowest in miscanthus. This suggests that both species were taking up and/or leaching soluble salts from miscanthus media much more quickly, reducing its EC. Additionally, as Altland [49] found, in general substrates made from bioenergy crops have pH values higher than recommended. In both species, pH tends to be higher in Basacote fertilizer and lower in Basacote + YaraMila, while EC was highest in Basacote + YaraMila and lowest in YaraMila. Such high EC values in both *Sedum* and *Hydrangea* can be affected by soluble salts uptake in these species. Hicklenton and Cairns [50] noticed that the EC of juniper container leachate was higher than in cotoneaster and suggested that available nutrients were not absorbed as readily by juniper.

Nutrients in substrates of *Sedum* (Table 14) tend to show the highest contents in 100% and 70% peatmoss media, while in *Hydrangea* (Table 15) they were spread among the substrates. In *Sedum,* the substrate × fertilizer treatment that affected the highest N, nitrates and K was 70% peatmoss with Basacote + YaraMila, and for Ca and Mg 50% peatmoss with YaraMila. *Hydrangea* had the highest P level in miscanthus straw. Frangi et al. [46] noted that P content increased when *Arundo donax* and *Miscanthus sinensis* rate in the medium was higher. However, *Sedum* in our own research did not fall into this pattern and had the highest P content in 100% peatmoss. As mentioned by Evans et al. [51], nutrients in rice hulls and other compost amendments can display varying degrees of extractability when mixed in the media, due to complex interactions between media components. Furthermore, these interactions can explain some of the discrepancies between nutrients measured in different blends [48].

Table 12. pH and EC of substrates in *Sedum spectabile* 'Stardust' grown in containers with five different substrates.

Substrate (A)	Fertilization (B)			
	Basacote	Basacote + YaraMila	YaraMila	Mean A
	pH			
100% P	6.5 ab	5.3 h	5.7 fg	5.8 d
70%P + 30%M	5.6 g	5.7 fg	5.8 f	5.7 d
50%P + 50%M	6.0 de	6.1 d	6.4 bc	6.1 c
30%P + 70%M	6.4 bc	6.2 bc	6.5 ab	6.4 b
100%M	6.6 a	6.3 cd	6.6 a	6.5 a
Mean B	6.2 a	5.9 b	6.2 a	
	EC (mS/cm)			
100% P	893 bc	1447 a	645 g	995 a
70%P + 30%M	823 d	888 c	623 g	778 c
50%P + 50%M	691 f	780 e	910 b	794 b
30%P + 70%M	430 i	671 f	376 j	493 d
100%M	302 k	534 h	369 j	402 e
Mean B	628 b	864 a	585 c	

(A) composed of various combinations of peatmoss (P) and miscanthus straw (M), along with one of three fertilizers (B), including either Basacote (15-11-13) or water soluble YaraMila Complex (12-5-15), either alone or in combination. Different lower case letters within mean A, mean B and A × B interaction indicate statistically significant differences at the significance level of ($p < 0.05$) by Fisher's test.

Table 13. pH and EC of substrates in *Hydrangea arborescence* 'Annabelle' grown in containers with five different substrates.

Substrate (A)	Fertilization (B)			
	Basacote	Basacote + YaraMila	YaraMila	Mean A
	pH			
100% P	8.4 a	7.9 b	7.7 bc	8.0 a
70%P + 30%M	7.7 bc	7.4 de	7.5 cd	7.5 b
50%P + 50%M	7.2 ef	7.1 f	7.3	7.2 c
30%P + 70%M	7.4 de	7.3 ef	7.3 ef	7.3 c
100%M	7.4 de	7.1 f	7.4 de	7.3 c
Mean B	7.6 a	7.4 b	7.5 b	
	EC (mS/cm)			
100% P	605 e	742 c	669d	672 a
70%P + 30%M	493 f	796 a	430h	572 c
50%P + 50%M	751 b	795 a	440g	662 b
30%P + 70%M	353 j	411 i	337k	367 d
100%M	191 l	339 k	168m	233 e
Mean B	478 b	617 a	408 c	

(A) composed of various combinations of peatmoss (P) and miscanthus straw (M), along with one of three fertilizers (B), including either Basacote (15-11-13) or water soluble YaraMila Complex (12-5-15), either alone or in combination. Different lower case letters within mean A, mean B and A × B interaction indicate statistically significant differences at the significance level of ($p < 0.05$) by Fisher's test.

Table 14. Substrate nutrient contents in *Sedum spectabile* 'Stardust' grown in containers with five different substrates.

Substrate (A)	Fertilization (B)			
	Basacote	Basacote + YaraMila	YaraMila	Mean A
	N Total (% d.w.)			
100% P	1.59 e	1.86 ab	1.75 cd	1.73 a
70%P + 30%M	1.51 e	1.97 a	1.85 bc	1.78 a
50%P + 50%M	1.60 e	1.79 bcd	1.56 e	1.65 b
30%P + 70%M	1.52 e	1.74 d	1.72 d	1.66 b
100%M	1.50 e	1.39 f	1.60 e	1.50 c
Mean B	1.54 c	1.75 a	1.70 b	
	NO_3^- (mg/dm^3)			
100% P	17.0 efg	10.7 h	18.3 e	15.3 d
70%P + 30%M	15.3 g	46.3 a	17.3 ef	26.3 a
50%P + 50%M	22.3 bc	20.3 d	22.7 b	21.8 b
30%P + 70%M	16.3 fg	20.3 d	20.7 cd	19.1 c
100%M	5.7 i	4.3 i	5.3 i	5.1 d
Mean B	15.3 c	20.4 a	16.9 b	
	P (mg/dm^3)			
100% P	23 k	116 e	66 h	69 d
70%P + 30%M	39 j	100 f	228 a	122 a
50%P + 50%M	17 l	127 c	88 g	77 c
30%P + 70%M	23 k	123 d	86 g	77 c
100%M	53 i	118 e	162 b	111 b
Mean B	31 c	117 b	126 a	
	K (mg/dm^3)			
100% P	57 e	183 a	53 ef	98 a
70%P + 30%M	53 ef	123 b	83 d	87 b
50%P + 50%M	57 e	117 b	50 ef	74 c
30%P + 70%M	43 f	97 c	27 g	56 e
100%M	93 cd	57 e	53 ef	68 d
Mean B	61 b	115 a	53 c	
	Ca (mg/dm^3)			
100% P	1193 d	997 h	1123 f	1104 c
70%P + 30%M	1197 d	963 i	1083 g	1081 d
50%P + 50%M	1223 c	1356 b	1473 a	1351 a
30%P + 70%M	1160 e	1227 c	1167 e	1184 b
100%M	483 j	343 l	403 k	410 e
Mean B	1051 a	977 b	1050 a	
	Mg (mg/dm^3)			
100% P	119 g	128 f	163 b	136 a
70%P + 30%M	116 g	150 c	145 d	137 a
50%P + 50%M	117 g	129 f	168 a	138 a
30%P + 70%M	138 e	143d e	129 f	137 a
100%M	63 i	65 i	72 h	66 b
Mean B	111 c	123 b	135 a	

(A) composed of various combinations of peatmoss (P) and miscanthus straw (M), along with one of three fertilizers (B), including either Basacote (15-11-13) or water soluble YaraMila Complex (12-5-15), either alone or in combination. Different lower case letters within mean A, mean B and A × B interaction indicate statistically significant differences at the significance level of ($p < 0.05$) by Fisher's test.

Table 15. Substrate nutrient contents in *Hydrangea arborescence* 'Annabelle' grown in containers with five different substrates.

Substrate (A)	Fertilization (B)			
	Basacote	**Basacote + YaraMila**	**YaraMila**	**Mean A**
	N Total (% d.w.)			
100% P	2.89 cdef	3.60 ab	3.64 ab	3.37 a
70%P + 30%M	2.53 efg	4.05 a	3.48 b	3.35 a
50%P + 50%M	2.89 cdef	3.94 a	2.93 cde	3.25 a
30%P + 70%M	2.86 def	3.33 bc	3.21 bcd	3.13 a
100%M	2.43 fg	2.17 ef	2.19 g	2.45 b
Mean B	2.67 c	3.53 a	3.14 b	
	NO_{3-} (mg/dm^3)			
100% P	12.2 h	10.6 i	12.6 h	11.8 d
70%P + 30%M	13.9 g	13.8 g	13.4 g	13.7 c
50%P + 50%M	28.7 a	18.0 f	27.1 b	24.6 a
30%P + 70%M	19.2 e	23.4 d	24.8 c	22.5 b
100%M	6.7 k	7.4 j	7.8 j	7.3 e
Mean B	16.1 b	14.6 c	17.2 a	
	P (mg/dm^3)			
100% P	27 k	45 i	87 e	53 d
70%P + 30%M	14 l	73g	54 h	47 e
50%P + 50%M	28 k	107 c	104 c	79 b
30%P + 70%M	25 k	79 f	100 d	68 c
100%M	42 j	163 a	144 b	116 a
Mean B	27 c	94 b	98 a	
	K (mg/dm^3)			
100% P	2633 f	3133 b	1317 l	2361 c
70%P + 30%M	2708 e	2767 d	3383 a	2953 a
50%P + 50%M	2508 g	2617 f	2833 c	2653 b
30%P + 70%M	2133 h	2133 h	2508 g	2258 d
100%M	1617 k	1816 j	1908 i	1781 e
Mean B	2320 c	2493 a	2390 b	
	Ca (mg/dm^3)			
100% P	3025 a	2100 de	1917f	2347 a
70%P + 30%M	2675 b	1758 g	1525h	1986 c
50%P + 50%M	2800 b	1525 h	1525 h	1950 cd
30%P + 70%M	2325 c	1867 fg	1525 h	1905 d
100%M	2200 cd	2050 e	1975 ef	2075 b
Mean B	2605 a	1860 b	1693 c	
	Mg (mg/dm^3)			
100% P	117 g	124 f	145 c	129 c
70%P + 30%M	116 g	141 cd	132 e	130 c
50%P + 50%M	137 d	165 a	153 b	151 a
30%P + 70%M	121 fg	166 a	117 g	134 b
100%M	39 j	68 h	46 i	51 d
Mean B	106 c	133 a	119 b	

(A) composed of various combinations of peatmoss (P) and miscanthus straw (M), along with one of three fertilizers (B), including either Basacote (15-11-13) or water soluble YaraMila Complex (12-5-15), either alone or in combination. Different lower case letters within mean A, mean B and A × B interaction indicate statistically significant differences at the significance level of ($p < 0.05$) by Fisher's test.

3. Materials and Methods

The research study was conducted at the Research Development Station of Wroclaw University of Environmental and Life Sciences. Plant trial was established in mid-May of

2014 and repeated for two consecutive years. A 5 × 3 factorial experiment was arranged in a randomized block design with a total of 15 treatments consisting of 24 plants each (eight plants in three replications).

3.1. Plant Material and Treatments

For the purpose of this research study, two plant species from different groups were selected: perennial *Sedum spectabile* 'Stardust' and woody shrub *Hydrangea arborescens* 'Annabelle'. Both species are commonly grown ornamental plants with high nutritional requirements. Plants were propagated at the Research Development Station of Wroclaw University of Environmental and Life Sciences in plugs and used in the form of rooted cuttings as the starting material for this study.

The two main factors in the research were substrate mix and fertilizer type.

The first factor was a substrate mixture composed of different proportions of peatmoss and shredded miscanthus straw:

100% peatmoss (control)
70% peatmoss + 30% miscanthus
50% peatmoss + 50% miscanthus
30% peatmoss + 70% miscanthus
100% miscanthus

The second factor was the two different fertilizer types: controlled released fertilizer Basacote (Basacote® Plus 6M 16-8-12(+2+TE); Compo) and water soluble YaraMila Complex (12 N(5 N-NO_3+7 N-NH_4+11 P_2O_5+18K_2O+2.7 MgO+20 SO_3+0.015 B+0.2 Fe+0.02 Mn+0.02 Zn; Yara), used separately and in a mix with different fertilization schemes:

3 g.dm^{-3} of Basacote premixed with each substrate mix
3 g.dm^{-3} of Basacote premixed with each substrate mix with YaraMila Complex top dressing, 3 times during vegetation period. at a dose of 1 g.dm^{-3}
1 g.dm^{-3} of YaraMila Complex premixed with each substrate mix with YaraMila Complex top dressing, 3 times during vegetation period, at a dose of 1 g.dm^{-3}

Fresh miscanthus straw (*Miscanthus* × *giganteus* Greef et Deu) was delivered from the experimental station of the Wroclaw University of Environmental and Life Sciences in Pawlowice, shredded in a hammermill and then screened to a particle size not exceeding 4 × 2 × 0.5 cm. To decrease the high carbon to nitrogen ratio in miscanthus close to the optimal level (24:1), shredded straw was premixed with YaraMila Complex (rate calculated based on N content of fertilizer and C:N ratio in starting material; data not shown). Peatmoss (sphagnum peatmoss, Klasmann) was mixed with miscanthus straw in proper ratios, samples of each substrate were taken to determine pH (Elmetron (CPI-501)), and then amended with the proper amount of lime to establish pH at the level of 6.2–6.5 based on the neutralization curve (data not shown). All five media were split into three piles and mixed with fertilizers: Basacote, Basacote with YaraMila, and YaraMila. Rooted cuttings of *Aster* and *Spiraea* were transplanted into 3 L pots filled with the proper substrate × fertilizer mix and placed in the outdoor nursery on black nursery fabric. Plants were trimmed by 1/3 height to stimulate shoot growth, and pots were fully saturated with water. Watering continued throughout the entire vegetation period until plants were ready to be measured. Irrigation was performed using overhead irrigation as needed, on average 3 times a week, with 300 mL of water per 1 dm^{-3} of substrate.

3.2. Plant Performance Measurements

For *Sedum*, measurements were taken in its full flowering stage, and for *Hydrangea*, by the end of the vegetation period. Biometric measurements for both species included:

plant height (measured from the level of substrate to the highest shoot)
plant diameter (measured at the widest and narrowest axis and averaged)

Additional *Hydrangea* measurements included:

main shoot number
main shoot length (measured for all main shoots and averaged)

Leaf performance of both species was tested on 8 randomly selected plants within the treatment and included:

leaf number (total leaves on both main and side shoots)
leaf blade length
leaf blade width
leaf blade area

Leaf blade length, width and area were tested on 15 leaves per plant, selecting mature, fully developed leaves in the central area of the plant, using a field portable leaf meter AM 300 (Opti-Sciences Inc., Hudson, NH, USA)

Additionally, for *Sedum*, the inflorescence number per plant, average inflorescence height and diameter were assessed. *Hydrangea* did not flower in the first year after planting.

Fresh shoot and root weight for both species was measured immediately after performing the above mentioned measurements. Dry weights were measured after drying above ground, and root biomass in the oven at 70 °C for 72 h.

3.3. *Leaf Analyses*

From each of the two tested species 20–25 leaves per plants within the substrate × fertilizer treatment (total of 8 randomly selected plants within each treatment) were collected and unified. Three subsamples from each treatment were subjected to testing:

in fresh material, chlorophyll a,b and total using spectrophotometry by Arnon [52]

leaf brightness and two color tones, using HunterLab MiniScan EZ working in CIE L * a * b * scale that was recalculated to RGB scale using color converter https://www.nixsensor.com/free-color-converter/ (accessed on 13 February 2023). Fresh leaf blades were spread flat on a white sheet, a reading head was placed on the leaf blade ensuring that the leaf surface covered the reading area, and measurements were taken and downloaded from the device

Chemical analyses of leaves included:

P and Mg by the colorimetric method of King [53] (Spectrophotometer S106 WPA),
K and Ca by flame photometry as in Toth and Prince [54] (Carl Zeiss Jena flame photometer),
NO_{3-} by flow colorimetry by Shinn [55].

3.4. *Substrate Analyses*

To perform chemical analyses of tested substrate mixes, 500 mL of substrate from 8 randomly selected plants within the substrate x fertilizer treatment of each species was collected and unified. Three subsamples from each treatment were subjected to testing: electrical conductivity (EC) measurements were made with a conductivity meter (Orion model 142) and pH of the soil with Elmetron (CPI-501) at a soil:distilled water ratio of 1:2. Total N was measured by the Kjedahl method, P and Mg by the colorimetric method (Spectrophotometer S106 WPA), K and Ca by flame photometry (Carl Zeiss Jena flame photometer), and NO_{3-} by flow colorimetry.

3.5. *Statistical Analysis*

The data were subjected to analysis of variance (ANOVA). The *F*-test was used to identify the treatments' main effects and interactions, followed by Fisher's range test at the 0.05 significance level using Statistica 13.3.721.0. As the research was conducted over three consecutive years and statistical analyses did not show significant differences between years, averaged data from 2014, 2015 and 2016 were analyzed and shown together.

4. Conclusions

Both *Sedum* and *Hydrangea* performed best in 100%P media and plant height decreased along with increase in miscanthus amendment. However, *Sedum* height in 50% miscanthus amended media was ~9% lower than in peatmoss and, for *Hydrangea* with 30% miscanthus amendment, this was ~9% lower than in peatmoss. A similar tendency was observed in both species with dry weights. Based on these results, it can be considered that, for *Sedum,* miscanthus amendment up to 50% and, for *Hydrangea,* up to 30% still produced plants with market value. EC and nutrient content in substrates decreased along with increase in miscanthus straw amendment in media. The lower water holding capacity of miscanthus straw suggests that the same irrigation frequency and amount could cause nutrient leaching, and further investigation is needed to develop more suitable practices for this media component.

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Miscanthus straw based media in nursery production of *Rudbeckia fulgida* ‘Goldstrum’ and *Thuja* ‘Smaragd’ – plant performance, nutritional status and selected substrate characteristics

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Abstract

Increasing horticultural production areas require increased volumes of soilless substrates. Uncertainty of availability and rising prices of commonly used media like peatmoss and pine bark are leading to an extended search for alternative growing media. The aim of this research was to test the suitability of fresh miscanthus straw shreds used separately and in substrate mixes in nursery production of the herbaceous perennial *Rudbeckia fulgida* ‘Goldsturm’ and woody shrub *Thuja* ‘Smaragd’. A total of five substrate mixes composed of peatmoss (P) and miscanthus straw (M) were used: 100% P, 70% P:30% M, 50% P:50% M, 30% P:70% M, 100% M. Each substrate was subjected to three fertilizer treatments: Basacote, Basacote+YaraMila and YaraMila. Across fertilizer type, *Thuja* had the greatest height in 30%P:70%M, while *Rudbeckia* had greater height and diameter in 100%P but larger leaf size and area in 50%P:50%M. Across substrate type, *Rudbeckia* had highest contents of chlorophyll a, chlorophyll b, and total chlorophyll when fertilized with Basacote+YaraMila. There were many discrepancies between foliar and substrate nutrient contents, possibly affected by an interaction between all media components. Thus, further investigation is needed for better understanding of miscanthus straw media amendment on ornamental plants in nursery production.

Keywords: growing media, miscanthus straw, nursery production, *Miscanthus ×giganteus* Greef et Deu, *Rudbeckia fulgida* 'Goldsturm', *Thuja* 'Smaragd'

Introduction

Greenhouse and nursery production are increasing worldwide to meet increasing demand for food and ornamental crops from the world's expanding population. Additionally, many field crops are transitioning into greenhouses or other forms of protected horticulture, especially in urban areas [1,2]. Container production provides more flexibility and control over external factors that affect yield and its quality, including availability of engineered growing media with physical and chemical characteristics targeting the needs of specific plants [3]. As a consequence of these changes, there is increasing demand for substrate components used in potting mixes.

Better understanding of human impact on the environment is pushing many industries towards using renewable resources and reducing the use of materials deemed unsustainable or detrimental to the environment. That includes, but is not limited to, using energy crops instead of fossil fuels [4, 5, 6], water saving technologies [7, 8, 9] and reduction in carbon footprint [10, 11]. Peatmoss, has been the primary component for soilless substrates for 60 years but has recently been deemed as an unrenewable and unsustainable resource [12]. As a result, many regions in the world have placed peatlands under legal protection in order to maintain this natural resource as a global carbon sink [13], and to reduce CO_2 emissions resulting from its harvest [14] . The uncertainty and unpredictability of the future of peatmoss are causing an urgent need to find and/or manufacture alternative substrate components.

Pine bark and coir are materials commonly used as growing media either alone or in combination with peatmoss [15, 16, 17]. Environmental concerns related to the way these two materials are obtained (e.g., timber reducing forest areas, carbon footprint of coir transportation) are moving the search for alternative growing media to greater sustainability and renewability. There were many studies on using different types of composted waste materials as a peatmoss alternative or component for soilless media, such as spent mushroom compost [18], manure from farm animals [19,20], or municipal solid waste [21,22]. Typically, substrates amended with greater than 20% to 30% by volume of compost will result in reduced plant growth depending on origin, composition, maturity and end use of the compost [23]. Additionally, the largest obstacle of their widespread use is maintaining a consistent an commercially-available supply and consistent quality. Another direction that is promising on a larger scale is the use of energy crops as substrate components. There have been several research studies on using willow species [24,25], wheat straw [26], or switchgrass [27,28] as substrate components. An energy crop that is gaining more attention as a prospective soilless substrate is miscanthus (*Miscanthus ×giganteus*). This tall C4 grass hybrid has high biomass production (10–25 t dry matter ha^{-1}) as well as being a low-input crop characterized by stable biomass and adequate biomass quantity [29]. As a sterile triploid hybrid, it cannot produce seeds which eliminates the risk of seed germination in miscanthus-straw based substrates. Miscanthus shreds and/or fibers were used as substrate in production of nursery shrubs [30, 31, 32,33,34], rooting wood cuttings [35] and also edible plants such as tomato and cucumber [36,37]. The objective of this research was to test different ratios of miscanthus straw with peat and fertilizer type amendment on substrate chemical properties and growth of two species representing different growth habits including a herbaceous perennial *Rudbeckia fulgida* ‘Goldsturm’ and a woody shrub *Thuja* ‘Smaragd’

Materials and methods

The research study was conducted at the Research Development Station of Wroclaw University of Environmental and Life Sciences. Plant trial was established mid-May and measurements and analyses were performed in the fall (mid-September, mid-October) of 2014 and repeated two consecutive years, 2015 and 2016. A 5x3 factorial experiment was arranged in a randomized block design, a total of 15 treatments consisting of 24 plants each (eight plants in three replications).

1. **Plant material and treatments**

For the purpose of this research study, two plant species from different groups were selected: herbaceous perennial *Rudbeckia fulgida* 'Goldsturm' and woody coniferous shrub *Thuja* ’Smaragd’ Plants were propagated at the Research Development Station of Wroclaw University of Environmental and Life Sciences in plugs and used in the form of rooted cuttings as the starting material for this study.

The two main factors in the research were substrate mix and fertilizer type.

First factor was substrate mixture composed of different proportions of peatmoss and shredded miscanthus straw:

- 100% peatmoss (control)
- 70% peatmoss + 30% miscanthus
- 50% peatmoss + 50% miscanthus
- 30% peatmoss + 70% miscanthus
- 100% miscanthus

Second factor was two different fertilizer types - controlled released fertilizer Basacote (15-11-13; Compo) and water soluble YaraMila Complex (12-5-15; Yara), used separately and in a mix with different fertilization schemes. Both fertilizers were selected based on their common use in nursery production of ornamental plants and fertilization schemes were based on the standard nursery practices related to the use of both fertilizers.

- $3\ g \cdot dm^{-3}$ of Basacote premixed with each substrate mix
- $3\ g \cdot dm^{-3}$ of Basacote premixed with each substrate mix with YaraMila Complex top dressing 3 times during the vegetation period at a dose of $1\ g \cdot dm^{-3}$
- $1\ g \cdot dm^{-3}$ of YaraMila Complex premixed with each substrate mix with YaraMila Complex top dressing 3 times during the vegetation period at a dose of $1\ g \cdot dm^{-3}$

Fresh miscanthus straw (*Miscanthus ×giganteus* Greef et Deu) was delivered from the experimental station of the Wroclaw University of Environmental and Life Sciences in Pawlowice, shredded in a hammermill and then screened to a particle size not exceeding 4x2x0.5 cm. To decrease high carbon to nitrogen ratio in miscanthus close to the optimal level (24:1), shredded straw was premixed with YaraMila Complex (rate calculated based on N content of fertilizer and C:N ratio in starting material; data not shown). Peatmoss (sphagnum peatmoss, Klasmann) was mixed with miscanthus straw in proper ratios, samples of each substrate were taken to determine pH and then amended with the proper amount of lime to establish pH at the level of 6.2-6.5 based on the neutralization curve (data not shown). All five media were split into three piles and mixed with fertilizers: Basacote, Basacote with YaraMila, and YaraMila. Rooted cuttings of *Rudbeckia* and *Thuja* were transplanted into 3L pots filled with proper substrate x fertilizer mix and placed in the outdoor nursery on black nursery fabric. Plants were trimmed by 1/3 height to stimulate shoot growth and pots were fully saturated with water. Watering continued throughout the entire vegetation period until plants were ready to be measured. Irrigation was performed using an overhead irrigation system as needed, on average 3 times a week with 300 ml water per 1 dm^{-3} of substrate.

2. **Plant performance measurements**

For *Rudbeckia*, measurements were taken in its full flowering stage, whereas for *Thuja* by the end of the vegetation period. Biometric measurements for both species included:

- plant height (measured from the level of the substrate to the highest shoot)
- plant diameter (measured at the widest and narrowest axis and averaged)

Due to differences in plant growth, additional biometric measurements of *Rudbeckia* were taken:

Leaf parameters were tested on 8 randomly selected plants within the treatment and included:

- number of leaves (total leaves on both main and side shoots)
- leaf blade length
- leaf blade width
- leaf blade area

Leaf blade length, width, and area were tested on 15 leaves per plant, selecting mature, fully developed leaves in the central area of the plant using a field portable leaf area meter AM 300 (Opti-Sciences Inc., Hudson, NH).

Flowering:

- inflorescence height
- number of composite flowers per inflorescence
- composite flower diameter
- % of flowering plants

Fresh shoot and root weight for both *Rudbeckia* and *Thuja* was measured right after performing the abovementioned measurements. Dry weights were measured after drying shoot and root biomass in the oven at 70°C for 72 hours.

3. **Leaf analyses**

To perform analyses, from each of the two tested species, 20-25 leaves per plant within the substrate x fertilizer treatment (a total of 8 randomly selected plants within treatment) were collected and unified. Three subsamples from each treatment were subjected to testing:

- chlorophyll a,a b, and total using spectrophotometry by Arnon [38]
- leaf brightness and two color tones using HunterLab MiniScan EZ working in CIE L*a*b* scale L* describing brightness (0 black, 100 white), a* tone green-red tone (negative green, positive red), b* tone (negative blue, positive yellow).

Chemical analyses of leaves included: P and Mg by the colorimetric method (Spectrophotometer S106 WPA), K and Ca by flame photometry (Carl Zeiss Jena flame photometer), and NO_3- by flow colorimetry.

4. **Substrate analyses**

To perform chemical analyses of tested substrate mixes, a total of 500ml of a substrate from 8 randomly selected plants within the substrate x fertilizer treatment of each species was collected and unified. Three subsamples from each treatment were subjected to testing. Electrical conductivity (EC) measurements were made with a conductivity meter Orion model 142 and the pH of the soil with Elmetron CPI-501 in soil:distilled water ratio 1:2., total N by Kjedahl method, P and Mg by the colorimetric method (Spectrophotometer S106 WPA), K and Ca by flame photometry (Carl Zeiss Jena flame photometer), and NO_3- by the flow colorimetry.

5. **Statistical analysis**

The data were subjected to the analysis of variance (ANOVA). The *F*-test was used to identify the treatments' main effects and interactions followed by Fisher's range test at the 0.05 significance level using Statistica 13.3.721.0. As the research was conducted in three consecutive years and statistical analyses did not show significant differences between years, averaged data from 2014, 2015 and 2016 were analyzed and shown together.

Results and discussion

1. Plant biometric characteristics

Rudbeckia had the tallest plants with the greatest diameter in 100%P media (Table 1), while *Thuja* was tallest in 30%P: 70%M and the widest in 100% P (Table 2). As noticed by Roosta and Afsharipoor [39], vigorous vegetative growth observed in peat is most likely due to higher nutrient uptake and the high water holding capacity in peat. Mustafa et al. [40] observed relatively minor differences in muskmelon seedlings height was with various proportions of wheat straw, although

50% blends produced the tallest plants. Both species had the shortest plants with the smallest diameter in miscanthus based growing media, however, for *Rudbeckia* differences in height between the tallest and shortest plants were around 50% (~ 15 cm), while for *Thuja* height differences were only about 20% (~ 2.5-3 cm). *Rudbeckia* and *Thuja* displayed an opposite reaction to fertilizer treatment where the shortest *Rudbeckia* were fertilized with Basacote, while the shortest *Thuja* received YaraMila. This might indicate that *Thuja*, as a species with slower growth than *Rudbeckia*, was not able to uptake the nutrients and benefit from the availability of readily soluble fertilizer, while faster growing *Rudbeckia* did not receive enough nutrients later in the experiment from more slowly released fertilizer. A similar observation was made by Hicklenton and Cairns [41] who reported slowly growing juniper ‘Plumosa Compacta’ was not able to absorb available nutrients as readily as the more rapidly growing cotoneaster ‘Coral Beauty’. The substrate x fertilizer interaction that caused *Rudbeckia* to be the shortest with the smallest diameter was 100%M with YaraMila, and 100%M with Basacote for *Thuja*.

Table 1. Selected biometric features of *Rudbeckia fulgida* 'Goldsturm' grown in containers with five different substrates (A) composed of various combination of peatmoss (P) and miscanthus straw (M), along with one of three fertilizers (B) including either Basacote (15-11-13) or water soluble YaraMila Complex (12-5-15) either alone or in combination. Different lower case letters within mean A, mean B and AxB interaction indicate statistically significant differences at the significance level ($p < 0.05$) by Fisher's test.

Substrate (A)	Fertilization (B)			
	Basacote	Basacote + YaraMila	YaraMila	Mean A
	Height (cm)			
100% P	24.7b	25.2ab	25.6a	25.2a
70%P + 30%M	17.3g	23.2c	19.6ef	20.0c
50%P + 50%M	19.9ef	23.6c	20.3e	21.3b
30%P + 70%M	14.1h	21.2d	19.1f	18.1d
100%M	12.9i	12.0i	10.6j	11.8e
Mean B	17.8c	21.1a	19.1b	
	Diameter (cm)			
100% P	37.5d	48.7a	42.0c	42.7a
70%P + 30%M	36.7d	45.9b	41.9c	41.5b
50%P + 50%M	34.6e	47.7ab	38.1d	40.1c
30%P + 70%M	26.6h	32.8ef	31.0f	30.1d
100%M	28.6g	31.6f	25.8h	28.7e
Mean B	32.8c	41.3a	35.8b	
	Leaves number			
100% P	18.7c	17.3d	18.7c	18.2b
70%P + 30%M	16.7d	23.0a	21.0b	20.2a
50%P + 50%M	11.4f	20.7b	14.0e	15.4c
30%P + 70%M	10.4g	18.7c	12.0f	13.7d
100%M	8.7h	12.0f	8.9h	9.8e
Mean B	13.2c	18.4a	14.9b	
	Leaf blade length (cm)			
100% P	12.17ef	13.05bcd	11.53g	12.25c
70%P + 30%M	13.00cd	13.25bc	12.64de	12.96b
50%P + 50%M	13.56b	14.30a	12.43ef	13.43a
30%P + 70%M	9.80ij	11.97fg	11.51g	11.09d
100%M	10.31hi	10.61h	9.64j	10.19e
Mean B	11.8b	12.6a	11.5c	
	Leaf blade width (cm)			
100% P	8.00ef	8.99bc	7.68f	8.22c
70%P + 30%M	8.11ef	9.25b	8.11ef	8.49b
50%P + 50%M	13..40a	9.33b	8.56cd	10.43a
30%P + 70%M	6.63g	8.17de	8.39de	7.73d
100%M	6.81g	6.91g	6.86g	6.86e
Mean B	8.59a	8.53a	7.92b	

	Leaf blade area (cm^2)			
100% P	64.66e	77.36c	59.31f	67.11c
70%P + 30%M	70.26d	84.05b	67.16de	73.83b
50%P + 50%M	119.25a	86.71b	75.23c	93.73a
30%P + 70%M	43.29h	64.35e	60.80f	56.14d
100%M	47.93g	50.44g	42.61h	47.00e
Mean B	69.08b	72.58a	61.02c	

Table 2. Selected biometric features of *Thuja* 'Smaragd' grown in containers with five different substrates (A) composed of various combination of peatmoss (P) and miscanthus straw (M), along with one of three fertilizers (B) including either Basacote (15-11-13) or water soluble YaraMila Complex (12-5-15) either alone or in combination. Different lower case letters within mean A, mean B and AxB interaction indicate statistically significant differences at the significance level ($p < 0.05$) by Fisher's test

Substrate (A)	Fertilization (B)			
	Basacote	Basacote + YaraMila	YaraMila	Mean A
	Height (cm)			
100% P	16.1de	15.2f	17.0bc	16.1c
70%P + 30%M	16.4cd	16.0def	15.4ef	15.9c
50%P + 50%M	17.5b	17.4b	15.3f	16.7b
30%P + 70%M	19.5a	17.2bc	16.9bc	17.9a
100%M	14.1g	15.9def	16.1de	15.3d
Mean B	16.7a	16.3b	16.2b	
	Diameter (cm)			
100% P	16.6a	14.4bc	15.0b	15.3a
70%P + 30%M	13.0f	13.8de	11.5h	12.8c
50%P + 50%M	12.9f	13.2ef	12.2gh	12.7c
30%P + 70%M	14.5bc	14.5bc	13.8cd	14.3b
100%M	10.7i	12.8fg	12.2g	11.9d
Mean B	13.5a	13.7a	13.0b	

Rudbeckia produced the greatest number of leaves in 70%P: 30%M and had the longest and widest leaf bade with the greatest leaf blade area in 50% P: 50%M media (Table 1). For *Rudbeckia*, all leaf parameters were the lowest in 100% M. Similarly, Bassan et al. [42] noticed that leaf number and leaf area of tomato transplants were negatively affected by increasing rice hull rates in the media. It is possible that leaf area decreased with decreasing water availability as has been observed in many crops including forage sorghum [43].

There was a clear pattern with fresh and dry weights of both tested species – *Rudbeckia* had the highest shoot and root weights in 100% P (Table 3), while *Thuja* in 70%P: 30%M (Table 4). Both species produced the lowest fresh and dry biomass in 100% M. These results are similar to those of Tsakaldimi and Ganatas [44] where the use of kenaf in media decreased the seedling biomass of three native species. In general, the biomass of both *Rudbeckia* and *Thuja* decreased with the increasing miscanthus straw amendment, similar to cherry laurel shoot dry weight with increasing *Arundo donax* and *Miscanthus sinensis* fiber in the growing medium [45]. Similar to plant height data, the difference between the highest and lowest shoot fresh weight was almost 4 times in *Rudbeckia*, while in *Thuja* only 1.5 times. This may indicate that lower water holding capacity in miscanthus media did not affect woody *Thuja* as much as it did herbaceous *Rudbekia*. For biomass production by *Rudbeckia*, the most favorable fertilizer was Basacote+YaraMila and for *Thuja* Basacote. Similar to the effect of media, the different reaction of these two plants is most likely related to their physiology where faster growing *Rudbeckia* benefited from both slow release and easy soluble fertilizer combination, while for slower growing *Thuja* the more slowly released fertilizer was optimal. The least favorable interaction of the two treatments for both species was miscanthus straw with YaraMila.

Table 3. Fresh and dry weight of *Rudbeckia fulgida* 'Goldsturm' grown in containers with five different substrates (A) composed of various combination of peatmoss (P) and miscanthus straw (M), along with one of three fertilizers (B) including either Basacote (15-11-13) or water soluble YaraMila Complex (12-5-15) either alone or in combination. Different lower case letters within mean A, mean B and AxB interaction indicate statistically significant differences at the significance level ($p < 0.05$) by Fisher's test.

Substrate (A)	Fertilization (B)			
	Basacote	Basacote + YaraMila	YaraMila	Mean A
	Shoot fresh weight (g)			
100% P	76.70f	140.87a	126.77b	114.78a
70%P + 30%M	95.07d	101.10c	98.93cd	98.37b
50%P + 50%M	82.80e	102.67c	59.10g	81.52c
30%P + 70%M	41.90i	81.17e	51.23h	58.10d
100%M	35.03j	18.47l	25.13k	26.21e
Mean B	66.3c	88.9a	72.2b	
	Root fresh weight (g)			
100% P	33.2.23d	42.57b	39.70c	38.17a
70%P + 30%M	31.27de	53.43a	29.87ef	38.19a
50%P + 50%M	29.27f	41.80b	19.87g	30.13b
30%P + 70%M	31.83d	39.27c	17.87h	29.66b
100%M	14.27i	16.70h	9.70j	13.56c
Mean B	27.8b	38.8a	23.4c	
	Shoot dry weight (g)			
100% P	20.23d	25.10a	23.13b	22.82a
70%P + 30%M	17.60g	18.70ef	19.37de	18.56b
50%P + 50%M	21.9c	22.07b	10.57i	18.54b
30%P + 70%M	11.77h	18.03fg	11.0h	13.83c
100%M	12.47h	6.77j	7.40j	8.88d
Mean B	16.8b	18.3a	14.4c	
	Root dry weight (g)			
100% P	9.022d	10.26c	9.31d	9.60a
70%P + 30%M	10.46c	8.08e	7.74f	8.76b
50%P + 50%M	8.36e	11.77a	5.57g	8.57c
30%P + 70%M	5.26h	11.13b	4.94i	7.11d
100%M	5.36gh	4.42j	3.07k	4.28e
Mean B	7.7b	9.1a	6.1c	

Table 4. Fresh and dry weight of *Thuja* ‘Smaragd’ grown in containers with five different substrates (A) composed of various combination of peatmoss (P) and miscanthus straw (M), along with one of three fertilizers (B) including either Basacote (15-11-13) or water soluble YaraMila Complex (12-5-15) either alone or in combination. Different lower case letters within mean A, mean B and AxB interaction indicate statistically significant differences at the significance level ($p < 0.05$) by Fisher’s test.

Substrate (A)	Fertilization (B)			
	Basacote	Basacote + YaraMila	YaraMila	Mean A
	Shoot fresh weight (g)			
100% P	24.48c	23.08de	22.10ef	23.22b
70%P + 30%M	30.34a	26.50b	21.15fg	26.00a
50%P + 50%M	20.24ij	20.35i	20.66h	20.41d
30%P + 70%M	24.19cd	19.93j	20.89g	21.67c
100%M	11.93l	20.55h	14.18k	15.55e
Mean B	22.32a	22.11a	19.80b	
	Root fresh weight (g)			
100% P	16.92bc	11.75f	11.16f	12.94d
70%P + 30%M	16.52b	12.75e	11.55f	13.59c
50%P + 50%M	15.92bc	13.71d	13.62d	14.41b
30%P + 70%M	18.09a	12.67e	15.92bc	15.56a
100%M	10.13g	15.18c	9.59g	11.63e
Mean B	15.32a	13.25b	12.43c	
	Shoot dry weight (g)			
100% P	9.41b	7.73f	7.30gh	8.15b
70%P + 30%M	8.53d	16.68a	8.11e	11.10a
50%P + 50%M	8.16e	7.15h	7.41gh	7.57d
30%P + 70%M	9.02c	7.53fg	7.30gh	7.95c
100%M	4.52j	8.21de	4.90i	5.87e
Mean B	7.93b	9.54a	7.00c	
	Root dry weight (g)			
100% P	4.00d	2.69f	2.41g	3.03d
70%P + 30%M	3.99d	6.49b	3.89d	4.79a
50%P + 50%M	6.76a	2.99e	2.46g	4.07b
30%P + 70%M	4.50c	3.09e	3.12e	3.57c
100%M	2.69f	3.88d	2.13h	2.90e
Mean B	4.42a	3.89b	2.8c	

The highest inflorescence and the highest percent of flowering plants were *Rudbeckia* grown in 100% P. The most composite flowers with the greatest diameter were observed in 70% P: 30%M (Table 5). Harris et al. [46] observed that petunia at the end of production phase had the lowest flower number in peat:wood and peat:fiber media compared to peat:coir mixes. Basacote+YaraMila fertilizer had the most beneficial effect on floral parameters. On the other hand, Starr et al. [47] found that increasing starter fertilizer decreased marigold (*Tagetes patula* L.) flower count. The lowest values of all tested generative parameters were found in 100% Mand the least favorable factor interaction were media containing 70% and 100% miscanthus straw with YaraMila.

Table 5. Flowering of *Rudbeckia fulgida* ‘Goldsturm’ grown in containers with five different substrates (A) composed of various combination of peatmoss (P) and miscanthus straw (M), along with one of three fertilizers (B) including either Basacote (15-11-13) or water soluble YaraMila Complex (12-5-15) either alone or in combination. Different lower case letters within mean A, mean B and AxB interaction indicate statistically significant differences at the significance level ($p < 0.05$) by Fisher’s test.

Substrate (A)	Fertilization (B)			
	Basacote	Basacote + YaraMila	YaraMila	Mean A
	Inflorescence height (cm)			
100% P	38.5a	34.1b	28.8d	33.8a
70%P + 30%M	33.6b	30.0c	34.0b	32.6b
50%P + 50%M	24.9e	18.6f	18.7f	20.8c
30%P + 70%M	0h	16.7g	0h	5.6d
100%M	0h	0h	0h	0e
Mean B	19.4b	19.9a	16.3c	
	Number of composite flowers per inflorescence			
100% P	6.4d	7.7b	7.8b	7.3b
70%P + 30%M	6.0e	7.4c	10.3a	7.9a
50%P + 50%M	5.1f	3.5g	3.1h	3.9c
30%P + 70%M	0i	3.3h	0i	1.1d
100%M	0i	0i	0i	0e
Mean B	3.5c	4.4a	4.2b	
	Composite flower diameter (cm)			
100% P	6.7d	7.0cd	7.1bc	6.9b
70%P + 30%M	6.8d	7.6a	7.3b	7.2a
50%P + 50%M	6.4e	7.2bc	7.1bc	6.9b
30%P + 70%M	0g	5.0f	0g	1.7d
100%M	0g	0g	0g	0e
Mean B	4.0c	5.3a	4.3b	
	% of flowering plants			
100% P	33g	74a	53d	53a
70%P + 30%M	38f	65b	48e	50b
50%P + 50%M	34g	56c	33g	41c
30%P + 70%M	0i	16h	0i	5d
100%M	0i	0i	0i	0e
Mean B	21c	42a	27b	

2. Leaf analyses

Rudbeckia had the darkest leaves (L*) with the bluest tone (b*) in Basacote+YaraMila (Table 6). This darker and bluer color is also expressed in chlorophyll contents that were highest in this fertilizer treatment (Table 7). For chlorophyll contents in *Thuja* there was clear trend, where all chlorophylls had the highest values in 70%P: 30%M media, including both the main factor mean for Basacote+YaraMila fertilizer and in interaction between Basacote+YaraMila and 70%P: 30%M (Table 8). In contrast, Starr et al. [47] found that in Chinese pistache (*Pistacia chinensis*) leaf greenness, as indicated by relative foliar chlorophyll content (SPAD), did not differ based on substrate or fertilizer. Likewise, Fain et al. [48] reported no effect from neither substrate nor starter fertilizer rate on leaf greenness of petunia (*Petunia ×hybrida* Vilm.).

Table 6. Leaf color of *Rudbeckia fulgida* 'Goldsturm' grown in containers with five different substrates (A) composed of various combination of peatmoss (P) and miscanthus straw (M), along with one of three fertilizers (B) including either Basacote (15-11-13) or water soluble YaraMila Complex (12-5-15) either alone or in combination. Numerical values of parameter L* (lightness), tone a* (green-red) and tone b* (blue-yellow) were analyzed statistically to find significant differences at the level of probability ($p < 0.05$) by Fisher's test (data not shown).

Substrate (A)	Fertilization (B)			
	Basacote	Basacote + YaraMila	YaraMila	Mean A
	L*			
100% P	30.6cde	29.2ab	33.3g	31.0a
70%P + 30%M	31.8ef	28.0a	32.5fg	30.8a
50%P + 50%M	33.1g	29.5bc	31.4def	31.3a
30%P + 70%M	33.4g	30.5cd	33.6g	32.5b
100%M	31.5def	31.7def	33.6g	32.3b
Mean B	32.1b	29.8a	32.9b	
	a			
100% P	-11.9de	-11.0gh	-10.3i	-11.1d
70%P + 30%M	-12.2bcd	-10.5hi	-12.6abc	-11.8b
50%P + 50%M	-12.1cde	-11.4fg	-12.9a	-12.1a
30%P + 70%M	-12.1cde	-10.5hi	-12.7ab	-11.8b
100%M	-11.8def	-11.0gh	-11.6ef	-11.5c
Mean B	-12.0a	-10.9b	-12.0a	
	b			
100% P	21.9de	19.3b	24.3h	21.8a
70%P + 30%M	24.2gh	17.1a	36.8j	26.0c
50%P + 50%M	26.1i	20.6c	25.6hi	24.1b
30%P + 70%M	26.5i	20.8cd	24.4h	23.9b
100%M	25.0h	22.4ef	23.2fg	23.5b
Mean B	24.8b	20.0a	26.9c	

Table 7. Chlorophyll contents (mg/g) in leaves of *Rudbeckia fulgida* 'Goldsturm' grown in containers with five different substrates (A) composed of various combination of peatmoss (P) and miscanthus straw (M), along with one of three fertilizers (B) including either Basacote (15-11-13) or water soluble YaraMila Complex (12-5-15) either alone or in combination. Different lower case letters within mean A, mean B and AxB interaction indicate statistically significant differences at the significance level ($p < 0.05$) by Fisher's test.

Substrate (A)	Fertilization (B)			
	Basacote	Basacote + YaraMila	YaraMila	Mean A
	Chlorophyll a			
100% P	0.588d	0.951a	0.575d	0.705a
70%P + 30%M	0.534e	0.695c	0.536e	0.588b
50%P + 50%M	0.441gh	0.729b	0.591d	0.595b
30%P + 70%M	0.464fg	0.537e	0.429h	0.513c
100%M	0.486f	0.539e	0.515e	0.469d
Mean B	0.503c	0.690a	0.529b	
	Chlorophyll b			
100% P	0.368c	0.564a	0.350d	0.427a
70%P + 30%M	0.272h	0.379c	0.283h	0.311c
50%P + 50%M	0.258i	0.439b	0.319fg	0.339b
30%P + 70%M	0.223j	0.342de	0.254i	0.273e
100%M	0.224j	0.330ef	0.313g	0.289d
Mean B	0.269c	0.410a	0.304b	
	Total chlorophyll			
100% P	0.956d	1.515a	0.925e	1.132a
70%P + 30%M	0.806g	1.074c	0.819g	0.900c
50%P + 50%M	0.722h	1.169b	0.910e	0.934b
30%P + 70%M	0.664i	0.879f	0.684i	0.742e
100%M	0.710h	0.869f	0.828g	0.802d
Mean B	0.771c	1.101a	0.833b	

Table 8. Chlorophyll contents (mg/g) in leaves of *Thuja* 'Smaragd' grown in containers with five different substrates (A) composed of various combination of peatmoss (P) and miscanthus straw (M), along with one of three fertilizers (B) including either Basacote (15-11-13) or water soluble YaraMila Complex (12-5-15) either alone or in combination. Different lower case letters within mean A, mean B and AxB interaction indicate statistically significant differences at the significance level ($p < 0.05$) by Fisher's test.

Substrate (A)	Fertilization (B)			
	Basacote	Basacote + YaraMila	YaraMila	Mean A
	Chlorophyll a			
100% P	0.348g	0.506c	0.354g	0.402d
70%P + 30%M	0.534b	0.606a	0.475de	0.538a
50%P + 50%M	0.480de	0.550b	0.428f	0.486b
30%P + 70%M	0.358g	0.493cde	0.440f	0.430c
100%M	0.344g	0.500cd	0.471e	0.438c
Mean B	0.413c	0.531a	0.433b	
	Chlorophyll b			
100% P	0.154i	0.249cd	0.181gh	0.195e
70%P + 30%M	0.246d	0.281a	0.205f	0.244a
50%P + 50%M	0.254bcd	0.263b	0.191g	0.236b
30%P + 70%M	0.173h	0.236e	0.208f	0.206d
100%M	0.182gh	0.256bc	0.247cd	0.228c
Mean B	0.202c	0.257a	0.206b	
	Total chlorophyll			
100% P	0.502k	0.755cde	0.536j	0.598e
70%P + 30%M	0.780c	0.887a	0.680g	0.782a
50%P + 50%M	0.733def	0.813b	0.619i	0.722b
30%P + 70%M	0.531j	0.729ef	0.647h	0.636d
100%M	0.526jk	0.756cd	0.718f	0.666c
Mean B	0.615c	0.788a	0.640b	

Foliar nutrient levels were generally higher in *Rudbeckia* cultivated in 50% or less miscanthus amendment (Table 9). For *Thuja* the highest concentrations of NO_3^-, P and K were found in 100% P (Table 10). *Thuja* had the highest leaf contents of P, K and Mg when fertilized with Basacote+YaraMila. Foliar nutrient concentrations, despite statistical differences among treatments, did not show a consistent pattern within species or between *Rudbeckia* and *Thuja*. That can indicate, as suggested by Mustafa et al. [40], that different media amendments can display different extractability due to the many interactions between media components causing discrepancies between substrate and foliar nutrient levels. Hicklenton and Cairns [41] did not show any reaction to fertilizer type in regards to foliar nutrient concentration with cotoneaster and juniper, but increasing fertilizer rate increased foliar N, P and K concentrations in cotoneaster, similarly as *Rudbeckia* had the highest nitrates concentration when fertilized with Basacote+YaraMila.

Table 9. Foliar nutrient contents (in dry mass) in *Rudbeckia fulgida* 'Goldsturm' grown in containers with five different substrates (A) composed of various combination of peatmoss (P) and miscanthus straw (M), along with one of three fertilizers (B) including either Basacote (15-11-13) or water soluble YaraMila Complex (12-5-15) either alone or in combination. Different lower case letters within mean A, mean B and AxB interaction indicate statistically significant differences at the significance level ($p < 0.05$) by Fisher's test.

Substrate (A)	Fertilization (B)			
	Basacote	Basacote + YaraMila	YaraMila	Mean A
	$N\text{-}NO_3^-$ (mg/g)			
100% P	15.0bcde	16.7a	15.0bcde	15.6a
70%P + 30%M	14.7defg	15.7abcd	16.3ab	15.6a
50%P + 50%M	16.0abc	14.7defg	15.3bcde	15.6a
30%P + 70%M	14.0fghi	14.3efgh	13.7ghi	14.0b
100%M	14.3efgh	13.0i	13.3hi	13.6b
Mean B	14.8a	14.9a	14.7a	
	P (mg/100g)			
100% P	128f	156e	117g	134c
70%P + 30%M	163e	228b	244a	212a
50%P + 50%M	118g	119g	203d	147b
30%P + 70%M	94j	115gh	105i	105d
100%M	128f	110hi	212c	150b
Mean B	126c	145b	176a	
	K (mg/100g)			
100% P	1425d	2117a	1568c	1703a
70%P + 30%M	1217f	1458d	1650b	1442b
50%P + 50%M	1225ef	1483d	1417d	1375c
30%P + 70%M	1008h	1675b	1300e	1328d
100%M	1008h	1300e	1067g	1125e
Mean B	1177c	1607a	1400b	
	Ca (mg/100g)			
100% P	3967b	2775fg	3467c	3403c
70%P + 30%M	4200a	3833b	3575c	3869a
50%P + 50%M	3925b	3292d	3300d	3506b
30%P + 70%M	3033e	2908ef	3192d	3044d
100%M	3825b	2825f	2667g	3106d
Mean B	3790a	3127c	3240b	

	Mg (mg/100g)			
100% P	17k	54b	35g	35d
70%P + 30%M	73a	30h	39e	48a
50%P + 50%M	49c	48c	43d	46b
30%P + 70%M	40e	37f	35g	37c
100%M	30h	21j	26i	26e
Mean B	42a	38b	36c	

Table 10. Foliar nutrient contents (in dry mass) in *Thuja* 'Smaragd' grown in containers with five different substrates (A) composed of various combination of peatmoss (P) and miscanthus straw (M), along with one of three fertilizers (B) including either Basacote (15-11-13) or water soluble YaraMila Complex (12-5-15) either alone or in combination. Different lower case letters within mean A, mean B and AxB interaction indicate statistically significant differences at the significance level ($p < 0.05$) by Fisher's test.

Substrate (A)	Fertilization (B)			
	Basacote	Basacote + YaraMila	YaraMila	Mean A
	N-NO_3^- (mg/g)			
100% P	12.1b	10.7fg	11.9bc	11.6a
70%P + 30%M	10.0i	10.9ef	10.5gh	10.4d
50%P + 50%M	10.2hi	11.1e	11.6cd	11.0c
30%P + 70%M	10.2hi	11.4d	12.4a	11.4b
100%M	10.3h	10.7fg	10.5gh	10.5d
Mean B	10.5c	11.0b	11.4a	
	P (mg/ 100g)			
100% P	250d	358a	132j	247a
70%P + 30%M	170h	225e	2010f	202d
50%P + 50%M	203f	283c	225e	238b
30%P + 70%M	158i	228e	3011b	232c
100%M	166hi	225e	191g	194e
Mean B	190c	264a	214b	
	K (mg/100g)			
100% P	2475bcd	2567ab	2767a	2603a
70%P + 30%M	1400ij	2375bcde	2200ef	1992c
50%P + 50%M	1575hi	2117fg	2383def	1991c
30%P + 70%M	1350j	2517bc	2308cdef	2058b
100%M	1317j	1958g	1633h	1636d
Mean B	1623c	2307a	2238b	

	Ca (mg/100g)			
100% P	2333a	1692d	1342h	1789b
70%P + 30%M	1600e	1383gh	1450fg	1478c
50%P + 50%M	1675de	1958bc	1600e	1744b
30%P + 70%M	2033b	1517f	1733d	1761b
100%M	1725d	1925c	1933c	1861a
Mean B	1873a	1695b	1612c	
	Mg (mg/100g)			
100% P	171jk	213ef	236c	207b
70%P + 30%M	190g	2010f	188gh	196d
50%P + 50%M	178ij	259b	167k	202c
30%P + 70%M	163k	290a	224d	225a
100%M	206f	220de	181hi	202c
Mean B	181c	238a	199b	

3. Substrate analyses

EC values were highest in both species in 100%P, however, substrates with *Thuja* were noticeably lower than substrates with *Rudbeckia* (Table 11, Table 12). Substrate EC is primarily affected especially by higher NO_3^- and K concentrations in substrates with *Rudbeckia* compared to *Thuja* (Table 13, Table 14). Additionally, K concentration in Thuja substrates were generally lower than *Rudbeckia* substrates. De Neve et al. [49] suggested that the exchange of K cations for other cations can result in lower EC. Substrate pH in *Rudbeckia* was highest in 50%P:50%M and for *Thuja* in 100%P. In both species, pH was the highest in Basacote and the lowest in Basacote+YaraMila, while the EC had the opposite trend with the highest values in Basacote+YaraMila and lowest values in Basacote. The highest EC in both species occurred in 100%P with Basacote+YaraMila. Soluble salts delivered from two fertilizer types were retained in peatmoss media in greater quantities than in miscanthus which was more prone to leaching.

Table 11. pH and EC of substrates in *Rudbeckia fulgida* 'Golsturm' grown in containers with five different substrates (A) composed of various combination of peatmoss (P) and miscanthus straw (M), along with one of three fertilizers (B) including either Basacote (15-11-13) or water soluble YaraMila Complex (12-5-15) either alone or in combination. Different lower case letters within mean A, mean B and AxB interaction indicate statistically significant differences at the significance level ($p < 0.05$) by Fisher's test.

Substrate (A)	Fertilization (B)			
	Basacote	Basacote + YaraMila	YaraMila	Mean A
	pH			
100% P	6.7ef	5.6h	6.2g	6.2d
70%P + 30%M	6.9cde	6.2g	6.9de	6.7c
50%P + 50%M	7.0bcde	7.1abcd	7.4a	7.2a
30%P + 70%M	7.3ab	6.5f	7.2abc	7.0b
100%M	7.1abcd	6.5f	6.5f	6.7c
Mean B	7.0a	6.3c	6.8b	
	EC (µS/cm)			
100% P	410d	604a	425cd	480a
70%P + 30%M	336f	594a	437c	456b
50%P + 50%M	288gh	371e	267i	309e
30%P + 70%M	272hi	475b	225j	324d
100%M	306g	485b	339f	377c
Mean B	322c	505a	339b	

Table 12. pH and EC of substrates in *Thuja* 'Smaragd' grown in containers with five different substrates (A) composed of various combination of peatmoss (P) and miscanthus straw (M), along with one of three fertilizers (B) including either Basacote (15-11-13) or water soluble YaraMila Complex (12-5-15) either alone or in combination. Different lower case letters within mean A, mean B and AxB interaction indicate statistically significant differences at the significance level ($p < 0.05$) by Fisher's test.

Substrate (A)	Fertilization (B)			
	Basacote	Basacote + YaraMila	YaraMila	Mean A
	pH			
100% P	8.4a	7.1b	6.6d	7.4a
70%P + 30%M	6.8c	6.3g	6.5e	6.5c
50%P + 50%M	6.3g	6.4f	6.4f	6.4c
30%P + 70%M	6.4f	6.7c	7.1b	6.7b
100%M	7.1b	6.7c	6.8c	6.9b
Mean B	7.0a	6.6b	6.7b	
	EC (µS/cm))			
100% P	283de	370a	309c	321a
70%P + 30%M	293d	337bb	317c	316a
50%P + 50%M	271e	343b	241g	285b
30%P + 70%M	270e	239g	256f	255c
100%M	146i	214h	122j	161d
Mean B	252b	301a	249b	

Although all nutrients were affected significantly by tested factors, there appeared to be no consistent trends between *Rudbeckia* and in *Thuja* except that YaraMila fertilizer resulted in the highest nutrient concentrations in the substrate (Table 13, Table 14). Gachukia and Evans [50], in their research on peat-based substrates amended with parboiled rice hulls or perlite, found that substrates containing rice hulls had higher NO_3^- levels than equivalent perlite-containing substrates. Likewise, substrates amended with miscanthus straw both in *Rudbeckia* and *Thuja* had the lowest total nitrogen and NO_3^- in 100% M straw and these parameters generally increased with decreasing miscanthus proportion in the substrate. Total N, NO_3^-, and P were the lowest in substrates containing *Thuja* fertilized with Basacote, which also contained plants with the lowest foliar contents of these nutrients and suggests that slow released fertilizer did not provide sufficient N and P for their uptake and/or both nitrates and phosphates were easy soluble and prone to leaching from irrigation. Gachukia and Evans [50] also noticed that substrate P and K increased with increasing of amount of parboiled rice hulls in the substrate.

A similar situation occurred in both *Rudbeckia* and *Thuja*, which had the highest P and K contents in 100% M. Similar findings were made by Frangi et al. [45] in that P and K content increased when *Arundo donax* and *Miscanthus sinensis* rate in the medium was higher. Mustafa et al. [40] likewise showed that wheat straw compost contributed P and K to substrate mixes.

Table 13. Substrate nutrient contents in *Rudbeckia fulgida* 'Golsturm' grown in containers with five different substrates (A) composed of various combination of peatmoss (P) and miscanthus straw (M), along with one of three fertilizers (B) including either Basacote (15-11-13) or water soluble YaraMila Complex (12-5-15) either alone or in combination. Different lower case letters within mean A, mean B and AxB interaction indicate statistically significant differences at the significance level ($p < 0.05$) by Fisher's test.

Substrate (A)	Fertilization (B)			
	Basacote	Basacote + YaraMila	YaraMila	Mean A
	N total (% d.w.)			
100% P	2.45h	3.77a	3.55b	3.26a
70%P + 30%M	2.28i	3.52bc	3.34d	3.05b
50%P + 50%M	3.21ef	3.45c	3.21ef	3.29a
30%P + 70%M	1.94j	3.30de	3.04g	2.76c
100%M	1.79k	3.18f	3.01g	2.66d
Mean B	2.33c	3.44a	3.23b	
	NO_3^- (mg/dm³)			
100% P	18.3def	31b	15.3g	21.6b
70%P + 30%M	17f	35.7a	18.0ef	23.6a
50%P + 50%M	22.7c	19.7d	22.0c	21.4b
30%P + 70%M	19.0de	14.0gh	13.3h	15.4c
100%M	6i	6i	6i	6.0d
Mean B	16.6b	21.3a	14.9c	
	P (mg/dm³)			
100% P	44h	48g	123b	72c
70%P + 30%M	46gh	119bc	117c	94b
50%P + 50%M	37i	50g	87e	58e
30%P + 70%M	25j	77f	103d	69d
100%M	81f	148a	149a	126a
Mean B	46c	89b	116a	
	K (mg/dm³)			
100% P	70g	110d	80f	87d
70%P + 30%M	100d	143bc	90e	111b
50%P + 50%M	90e	147b	60h	99c
30%P + 70%M	60h	140c	60h	87d
100%M	80f	183a	100d	121a
Mean B	80b	145a	78b	

	Ca (mg/dm³)			
100% P	1077d	857g	910f	948c
70%P + 30%M	947ef	1027d	1177c	1050b
50%P + 50%M	1237ab	1200bc	1267a	1234a
30%P + 70%M	967e	840g	933ef	913d
100%M	547h	567h	430i	514e
Mean B	955a	898c	943b	
	Mg (mg/dm³)			
100% P	81ef	85e	82ef	83c
70%P + 30%M	94d	122a	109b	108a
50%P + 50%M	96d	103c	79f	93b
30%P + 70%M	82ef	109b	82ef	91b
100%M	57h	55h	60g	57d
Mean B	82c	95a	83b	

Table 15. Substrate nutrient contents in *Thuja* 'Smaragd' grown in containers with five different substrates (A) composed of various combination of peatmoss (P) and miscanthus straw (M), along with one of three fertilizers (B) including either Basacote (15-11-13) or water soluble YaraMila Complex (12-5-15) either alone or in combination. Different lower case letters within mean A, mean B and AxB interaction indicate statistically significant differences at the significance level ($p < 0.05$) by Fisher's test.

Substrate (A)	Fertilization (B)			
	Basacote	Basacote + YaraMila	YaraMila	Mean A
	N total (% d.w.)			
100% P	2.15g	3.51b	3.39c	3.01b
70%P + 30%M	2.37f	3.36c	3.35c	3.03b
50%P + 50%M	2.24f	3.12d	3.08de	2.9c
30%P + 70%M	2.20fg	2.99e	4.77a	3.32a
100%M	1.89h	1.90h	1.17i	1.70d
Mean B	2.17c	2.98b	3.15a	
	NO_3^- (mg/dm³)			
100% P	16.3g	13.7h	18.3f	16.1d
70%P + 30%M	23.0d	14.2h	21.0e	19.5c
50%P + 50%M	25.0c	30.0b	29.7b	28.2b
30%P + 70%M	24.4c	29.5b	34.6a	29.5a
100%M	8.8i	8.9i	6.0j	7.9e
Mean B	19.5b	19.3b	21.9a	

	P (mg/dm³)			
100% P	45i	61h	110d	72c
70%P + 30%M	30k	69g	120c	73c
50%P + 50%M	34j	110d	125b	90b
30%P + 70%M	27k	105e	135a	89b
100%M	71g	135a	95f	101a
Mean B	42c	96b	117a	
	K (mg/dm³)			
100% P	40c	70a	30d	47a
70%P + 30%M	40c	60b	30d	43b
50%P + 50%M	30d	60b	20e	37c
30%P + 70%M	30d	30d	20e	27d
100%M	10f	40c	10f	20e
Mean B	30b	52a	22c	
	Ca (mg/dm³)			
100% P	1067ef	850g	1058f	992d
70%P + 30%M	1175de	875g	1117ef	1056c
50%P + 50%M	1350bc	1258cd	1442b	1350b
30%P + 70%M	1300c	1358bc	1625a	1428a
100%M	475h	383i	375i	411e
Mean B	1073b	945c	1123a	
	Mg (mg/dm³)			
100% P	106d	74f	115c	98c
70%P + 30%M	109d	81e	134b	108b
50%P + 50%M	85e	106d	150a	114a
30%P + 70%M	83e	105d	105d	98c
100%M	46h	57g	45h	50d
Mean B	86b	85b	111a	

Conclusions

Results obtained in the tested species show the potential for miscanthus straw as a component in container media. Considering the overall growth and appearance (foliar color and floral parameters), *Rudbeckia* plants had acceptable market value when grown in media with up to 50% miscanthus and *Thuja* with up to 70% miscanthus. There were many discrepancies between foliar and substrate nutrient contents, possibly affected by an interaction between all media components. However, foliar and substrate nutrient contents decreased with the increasing \miscanthus straw amendment in media. In the light of this observation, as irrigation was the same for all treatments, further studies on optimizing fertilization and irrigation when producing plants in miscanthus straw amended growing media are necessary to provide more detailed information on the practices needed for successful production in miscanthus based growing media.

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Plant performance, nutritional status and selected substrate characteristics of *Aster dumosus* 'Jenny' and *Spiraea densiflora* Nutt. ex Torr. et A. Gray. grown in miscanthus straw amended substrates

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Abstract

Horticultural production that relies mainly on peatmoss is facing many challenges. Due to the tremendous growth of nursery and greenhouse industries followed by increased demand for soilless media, the search for peatmoss substitutes increased in recent years. The aim of this research was to test the suitability of fresh miscanthus straw shreds used separately and in substrate mixes in nursery production of herbaceous perennial *Aster dumosus* 'Jenny' and woody shrub *Spiraea densiflora* Nutt. ex Torr. et A. Gray. Total five substrate mixes composed of peatmoss and miscanthus straw were used: 100%P, 70%P:30%M, 50%P:50%M, 70%P:30%M, 100%. Each substrate was subjected to three fertilizer treatments: Basacote, Basacote+YaraMila, and YaraMila. Growth response of both tested species was very similar. In general, plants were performing the best in 100%P and their quality was decreasing with the increase of miscanthus straw amendment. The most favorable fertilizer was the combination of Basacote+YaraMila as it delivered soluble salts from two different sources at higher rates than these fertilizers used separately. Values of pH were significantly higher in miscanthus amended media and the lowest in peatmoss, while the EC showed the opposite trend. In terms of foliar nutrition of tested plants, similar trends to growth response were found, where 100%P was the most favorable and the least 100%M. These results also found confirmation in chlorophylls contents and leaf color. In this research, 100% miscanthus straw media did not show suitability as peatmoss replacement, however, its mixes with peatmoss show potential. Further investigation is needed to adjust

fertilization and irrigation regimens to manage physical properties and bring them closer to these recommended for optimal growing condition in soilless media.

Keywords: growing media, miscanthus straw, *Miscanthus ×giganteus* Greef et Deu, *Aster dumosus* 'Jenny', *Spiraea densiflora* Nutt. ex Torr. et A. Gray.

Introduction

Horticultural substrates are formulated by mixing various organic and inorganic components in ratios that provide suitable physical and chemical properties adjusted to crop requirements and growing conditions. Peatmoss has been primary substrate and substrate amendment in soilless growing media for decades as its characteristics provides stable environment for greenhouse and nursery container production of ornamental and edible plants (Raviv et al., 1986 (Carlile et al., 2015; Robinson and Lamb, 1975). However, the increasing expense of peatmoss (Caron et al., 2015) altogether with increasing ecological awarenessthe of negative impact of peat exploitation on wetland ecosystems Barkham, 1993; Robertson, 1993, Cleary et al., 2005) are progressively limiting its use in horticultural production.

The search for peatmoss substitutes started almost 50 years ago. As one of the first, softwood and hardwood barks were introduced as main components of soilless substrates in nursery container production (Aaron, 1982; Hoitink and Poole, 1979) and since then are widespread and successfully used as peat alternative together with other wood materials, like wood chips (wood residue wastes (Riviere and Milhau, 1983) whole ground trees (Fain et al. 2008a, 2008b) wood fibers (Bohne, 2004; Lemaire et al., 1989, Harris et al. 2019, Durand et al. 2021). The most common are derivates from pine, nonetheless, there were some attempts to use different tree species for substrate production purposes, like douglas fir (Owen et al, 2009, Zazirska et al. 2009, Altland et al 2008), easter redcedar and hedge-apple (Starr et al. 2012, Starr et al 2013), melaluca (Conover and Poole 1983), post oak and Siberian elm (Kenna and Whitcomb 1985). However, shifts in forest industry are notably affecting not only price but also availability of bark and other wood materials for horticultural production, are leading substrate producing companies and growers themselves further into searching for peatmoss substitute.

Many research studies on testing and developing new growing media components were focused on using locally obtained raw materials that are agricultural, industrial and municipal waste products. These studies included, but were not limited to, vine pomace, urban waste and vegetable waste (Diaz-Perez and Comacho-Ferre 2010), solid fraction of olive mill wastewater and olive leaves (Garcia-Gomez et al. 2002), winery and distillery wastes (Bustamante et al 2008. Bustamante et al 2009), rice hulls (Miyama et al. 2009,Buck and Evans 2010), cotton gin compost (Jackson et al. 2005a,b), paper mill sludge (Chong and Lumis 2000), poultry litter and bovine manure compost (Marble et al, 2010, Tittarelli i in. 2009), and municipal solid waste compost (Giannakis and Kourgialas 2014, Moldes et al. 2007, Castillo et al. 2004). The disadvantage of these kinds of materials though, even when they seem to be economically and ecologically reasonable as sources for substate components, was related to their high variability and inconsistency, contamination, as well not enough quantities that could be obtained as stable and continuous supply on a bigger scale.

The promising source for substrate production can be plants grown until now mainly as energy crops. One of the energy plants, also used as ornamental, that can play a significant role in changing the growing media industry, is miscanthus (*Miscanthus ×giganteus*). As mentioned by Heaton et al. (2010), miscanthus can be cultivated in a sustainable way in terms of both ecology and economy. Additionally, the authors highlighted that miscanthus is one of the most productive land plants in temperate climate. Its biomass production and quality can be also managed through cultivation practices involving fertilization and harvest time, which can increase nutrient contents in the straw used for substrate production (Iqbal et al., 2015, Gołąb -Bogacz et al. 2021a,b).

Authors of this article, based on their previously conducted research studies with the use of miscanthus straw as growing medium (Babelewski and Pancerz 2018, Babelewski et al. 2019, Pancerz and Babelewski 2019, Babelewski and Pancerz 2018) and available literature on miscanthus straw use in nursery production (Kresten Jensen et al., 2000; Clemmensen, 2004; Altland 2010; Altland and Locke, 2011), decided to assess plants performance in miscanthus straw amended media on two selected ornamental species: perennial *Aster dumosus* 'Jenny' and woody shrub *Spiraea densiflora* Nutt. ex Torr. et A. Gray., followed by the chemical analysis of leaf tissues of tested species and substrate analyses.

Materials and methods

The research study was conducted at the Research Development Station of Wroclaw University of Environmental and Life Sciences. Plant trial was established in mid-May of 2014 and repeated for two consecutive years, 2015 and 2016. A 5x3 factorial experiment was arranged in a randomized block design, a total of 15 treatments consisting of 24 plants each (eight plants in three replications).

6. **Plant material and treatments**

For the purpose of this research study, two plant species from different groups were selected: herbaceous perennial *Aster dumosus* 'Jenny' and woody shrub *Spiraea densiflora* Nutt. ex Torr. et A. Gray. Plants were propagated at the Research Development Station of Wroclaw University of Environmental and Life Sciences in plugs and used in the form of rooted cuttings as the starting material for this study.

The two main factors in the research were substrate mix and fertilizer type.

First factor was substrate mixture composed of different proportion between peatmoss and shredded miscanthus straw:

- 100% peatmoss (control)
- 70% peatmoss + 30% miscanthus
- 50% peatmoss + 50% miscanthus
- 30% peatmoss + 70% miscanthus
- 100% miscanthus

Second factor were two different fertilizer types - controlled released fertilizer Basacote (15-11-13; Compo) and water soluble YaraMila Complex (12-5-15; Yara) , used separately and in a mix with different fertilization schemes:

- 3 g · dm^{-3} of Basacote premixed with each substrate mix
- 3 g · dm^{-3} of Basacote premixed with each substrate mix with YaraMila Complex top dressing 3 times during the vegetation period at a dose of 1 g · dm^{-3}
- 1 g · dm^{-3} of YaraMila Complex premixed with each substrate mix with YaraMila Complex top dressing 3 times during the vegetation period at a dose of 1 g · dm^{-3}

Fresh miscanthus straw (*Miscanthus* ×*giganteus* Greef et Deu) was delivered from the experimental station of the Wroclaw University of Environmental and Life Sciences in Pawlowice, shredded in a hammermill and then screened to the particle size not exceeding 4x2x0,5 cm. To decrease the high carbon to nitrogen ratio in miscanthus close to the optimal level (24:1), shredded straw was premixed with YaraMila Complex (rate calculated based on N content of fertilizer and C:N ratio in starting material; data not shown). Peatmoss (sphagnum peatmoss, Klasmann) was mixed with miscanthus straw in proper ratios, samples of each substrate were taken to determine pH and then amended with the proper amount of lime to establish pH at the level of 6.2-6.5 based on the neutralization curve (data not shown). All five media were split into three piles and mixed with fertilizers: Basacote, Basacote with YaraMila, and YaraMila. Rooted cuttings of *Aster* and *Spiraea* were transplanted into 3L pots filled with proper substrate x fertilizer mix and placed in the outdoor nursery on the black nursery fabric. Plants were trimmed by 1/3 height to stimulate shoot growth and pots were fully saturated with water. Watering continued throughout the entire vegetation period until plants were ready to be measured. Irrigation was performed using an overhead irrigation system as needed, on average 3 times a week with 300 ml per 1 dm^{-3} of water.

7. **Plant performance measurements**

For *Aster* measurements were taken in its full flowering stage, while for *Spiraea* by the end of the vegetation period. Biometric measurements for both species included:

- plant height (measured from the level of the substrate to the highest shoot)
- plant diameter (measured at the widest and narrowest axis and averaged)
- main shoot number
- main shoot length (measured for all main shoots and averaged)
- side shoots number (sum of all side shoots from main shoots)

Leaf performance of both species was tested on 8 randomly selected plants within the treatment and included:

- leaves number (total leaves on both main and side shoots)
- leaf blade length
- leaf blade width
- leaf blade area

Leaf blade length, width and area was tested on 15 leaves per plant, selecting mature, fully developed leaves in the central area of the plant using field portable leaf are meter AM 300 (Opti-Sciences Inc., Hudson, NH)

Additionally, for *Aster* flower number per plant, average flower diameter and percentage of flowering plants were assessed. *Spiraea* did not flower in the first year after planting.

Fresh aboveground and root weights for both species were measured right after performing the abovementioned measurements. Dry weights were measured after drying aboveground and root biomass in the oven at 70°C for 72 hours.

8. **Leaves analyses**

To perform analyses, from each of the two tested species 20-25 leaves per plant within the substrate x fertilizer treatment (a total of 8 randomly selected plants within treatment) were collected and unified. Three subsamples from each treatment were subjected to testing:

- chlorophyll a,b and total using spectrophotometry
- leaf brightness and two color tones using HunterLab MiniScan EZ working in CIE L*a*b* scale that was recalculated to RGB scale using color converter https://www.nixsensor.com/free-color-converter/

Chemical analyses of leaves included: P and Mg by the colorimetric method (Spectrophotometer S106 WPA), K and Ca by flame photometry (Carl Zeiss Jena flame photometer), and NO_3- by the flow colorimetry.

9. **Substrate analyses**

To perform chemical analyses of tested substrate mixes, 500ml of the substrate from 8 randomly selected plants within the substrate x fertilizer treatment of each species was collected and unified. Three subsamples from each treatment were subjected to testing: electrical conductivity (EC) was made with conductivity meter Orion model 142 and pH of the soil with Elmetron CPI-501 in soil: distilled water ratio 1:2., total N by Kjedahl method, P and Mg by the colorimetric method (Spectrophotometer S106 WPA), K and Ca by flame photometry (Carl Zeiss Jena flame photometer), and NO_3- by the flow colorimetry.

10. **Statistical analysis**

The data were subjected to the analysis of variance (ANOVA). The *F*-test was used to identify the treatments main effects and interactions followed by Fisher's range test at the 0.05 significance level using Statistica 13.3.721.0. As the research was conducted in three consecutive years and statistical analyses did not show significant differences between years, averaged data from 2014, 2015 and 2016 were analyzed and shown together.

Results and discussion

1. **Plant performance measurements**

1.1 Height, diameter and shoot growth

Substrate, fertilizer and substrate x fertilizer treatments had significant effect of tested biometrics of both *Aster* (Table 1) and *Spiraea* (Table 2). All tested parameters were the highest in both species grown in 100%P and the values had tendency to decrease with increasing amendment of miscanthus straw. There was also identical response of both *Aster* and *Spiraea* that were the smallest in height and diameter with the shortest main shoots when grown 100%M and the lowest number of main and side shoots in the mix containing 30% of miscanthus straw. Such results can be explained by lower water holding capacity of miscanthus straw and its lower value of easily available water in comparison to peat substrates (Clemmensen, 2004). Similar results were observed by Frangi et al. (2012), where cherry laurel and lauristinus showed reduced growth in media with 50% and 75% amendment of miscanthus straw. Authors highlighted that it can be affected by increasing the relative air volume with the increase of miscanthus rate in the medium, what results in an air volume higher than recommended for pot cultivation. Consistency of these results and statements was also mentioned by Harris et al. (2020), who suggested, that increasing pine wood to more than 30% of the volume may require adjustments in irrigation and fertilization practices due to changes in physical properties.

Both *Aster* and *Spiraea* grew the best when fertilized with both Basacote and YaraMila (Table 1,2). However, the lowest values of all tested biometric parameters were found in *Aster* fertilized with Basacote, while for *Spiraea* in YaraMila fertilization. As indicated by Hicklenton and Cairns (1992) in their research with cotoneaster and juniper cuttings fertilized with rapid and slowly releasing types of Nutricote, fertilizer rate had a stronger effect on cotoneaster growth influenced more by total available nutrient quantities during entire growing season rather than by availability at specific times what explains why performance of *Aster* and *Spiraea* was the best with the use of Basacote with YaraMila. Hicklenton and Cairns (1992) also stated that for recently propagated plants with few nutrient reserves, delivering enough available nutrients to establish proper nutritional status of tissues as early as possible can be detrimental in affecting subsequent growth. Following these findings, it seems that for *Aster* as herbaceous plant, slow released Basacote did not provide sufficient nutrition at the beginning, thus the most suppressed growth in this fertilizer treatment. On the other hand for woody *Spiraea* it was easily soluble YaraMila that did not provide sufficient nutrition, while plants fertilized with Basacote, despite statistical differences, had biometric measurements close to the values from Basacote+YaraMila treatment, was better nutrient source for this species.

With such uniform reaction of *Aster* and *Spiraea* to both factors, also interaction substrate x fertilizer had clear effect on both species (Table 1,2). The highest values of tested biometric features of both species were noted in 100% peatmoss with Basacote+YaraMila fertilizer, while the lowest for *Aster* in 100% and 70% miscanthus with Basacote and for *Spiraea* in 100% and 70% miscanthus with YaraMila fertilizer. As observed by Carthaigh et al. (1996) when growing *Hypericum* and *Ligustrum* in miscanthus, growth reduction can be due to increased fixation of nitrogen and reduction of its availability with increasing rates of miscanthus in growing media.

1.2 Leaves measurements

Response of *Aster* (Table 3) and *Spiraea* (Table 4) features of leaves is not as unified as previously described biometric features. However, there are still clear tendencies for *Aster* and *Spiraea* to reach the highest values in peatmoss and the lowest in 70% and 100% miscanthus, and in regards to fertilization the highest in Basacote with YaraMila for both species. Tendency observed in factor interactions for *Aster* was having the best quality leaves in peatmoss with Basacote fertilizer and significantly lower in miscanthus media containing 50% and more with Basacote fertilizer, and *Spiraea* had tendency to have the best quality leaves in mixes 50% peatmoss with 50% miscanthus with the use of Basacote and YaraMila. On the other hand, Kuisma et al. (2014) showed, that the leaf area of strawberry was the greatest in plants grown on coir, but did not differ significantly between peat, peat with reed canary grass or reed canary grass media.

1.3 Flowering

Aster (Table 5) had the most flowers in 70% peatmoss with 30% miscanthus media, while the less in 50% miscanthus amended mix. The highest flower diameter was found with treatments containing 0%, 30%, and 50% miscanthus straw and the less in 70% and 100% miscanthus media. Similar to vegetative biometric features, media containing higher volumes of miscanthus did not provide the sufficient environment for flower development.

Plants grown in Basacote produced the highest number of flowers, the biggest diameter of flowers was with the use of Basacote with YaraMila, and the highest percentage of flowering plants in both fertilization treatments containing easy soluble fertilizer – Basacote with YaraMila and YaraMila treatments.

Interaction between substrate and fertilizer did not provide unified results for tested flower features, however, the less favorable media for flowering were 100% miscanthus with the use of Basacote or YaraMila fertilizer.

1.4 Fresh and dry biomass

Aster (Table 6) and *Spiraea* (Table 7) obtained the highest aboveground and root weight, both fresh and dry, when cultivated in 100% peatmoss, while the lowest fresh and dry weight of aboveground part and roots was generally found in 100% miscanthus straw based media. There is also clear tendency of decrease in weight with the increase of miscanthus volume in the media. Pancerz and Babelewski (2019) in their previous research on hydrangea cultivation in miscanthus based growing media have shown that fresh shoot and root weight was the highest in peatmoss and was decreasing with the increase of miscanthus amendment. Frangi et al. (2012) obtained similar results, where the shoot dry weight of cherry laurel was negatively influenced when *Arundo donax* and *Miscanthus sinensis* fiber increased in the growing medium. Similarly, strawberry grown in peat had the highest aboveground dry weight when grown in peat in comparison to media containing coir or reed canary grass (Kuisma et al., 2014).

The most beneficial fertilization regimen for fresh and dry biomass accumulation for both tested species was the use of Basacote with YaraMila (Table 6,7), as this treatment provided more nutrients than these fertilizers used separately in substrate mixes. This statement finds confirmation in the research conducted by Fain et al. (2008), who found that the shoot dry weight of petunia grown in *WholeTree* amended media increased with increasing fertilizer rate.

Interaction that affected the highest biomass accumulation in both tested species was mainly peatmoss with the use of Basacote and YaraMila fertilizers (Table 6,7). Similar to biometric measurements, *Aster* responded by the lowest aboveground and root fresh and dry weight when cultivated in 100% miscanthus with Basacote fertilizer and *Spiraea* when grown in 100% miscanthus with the amendment of YaraMila.

1.5 Leaves analyses

1.5.1 Leaf color and chlorophyll contents

Aster (Table 8) had the darkest leaves with the most green tone when grown in media containing up to 50% miscanthus in the media, while the lightest leaves with the more yellow tone had plants grown in 70% miscanthus amendment. These values have also confirmation in chlorophyll concentrations that were the highest in peatmoss (Table 10). Additionally, chlorophyll b decreased with the increase of miscanthus amendment. For *Spiraea* (Table 9) substrate that affected the darkest leaves with the most blue color tone was peatmoss, which is, similarly as in *Aster*, followed by chlorophyll a, b and total concentrations that were the highest in peatmoss (Table 11). Contradictory findings were shown in strawberry cultivation in coir, peat, reed canary grass, and mix of peat with reed canary grass, where strawberry leaf chlorophyll content did not differ between the treatments (Kuisma eta al. 2014)

Both *Aster* (Table 8) and *Spiraea* (Table 9) had the darkest leaves with the most green tone and the most blue tone, containing the highest concentrations of chlorophylls when grown in Basacote and YaraMila. It is affected by the increased amount of nutrients, especially nitrogen and magnesium, coming from slow released fertilizer and easily soluble fertilizer used simultaneously in compare to these fertilizers used separately.

Also both species had the darkest leaves in with the most green tone in interaction 50% miscanthus with Basacote+YaraMila, even when all chlorophyll concentrations were the highest in peatmoss with Basacote+YaraMila. *Aster* had the lightest leaves with the less green and the most yellow tones in 70% miscanthus amended media with Basacote, confirmed by the lowest concentrations of chlorophyll in the same interaction treatment. *Spiraea* had the lightest leaves in 30% miscanthus amended media with YaraMila fertilizer, but the leaves were the most yellow in 50% miscanthus content with YaraMila. This color interpretation is not expressed in chlorophyll concentrations that had the lowest values in media containing 70% and 100% of miscanthus straw.

1.5.2 Foliar nutrient levels

There were no clear patterns of nutrients distribution in the leaf tissues of both *Aster* (Table 12) and *Spiraea* (Table 13). However, NO_3- and P were the highest in peatmoss. NO_3- content in both species was the lowest in miscanthus. Similar results were obtained Mustafa et al. (2016) in muskmelon transplants that showed a decrease in tissue N concentration with the increased proportion of wheat straw in the substrate. Lower foliar nutrient levels may be a consequence of microbial activity in lignocellulosic materials and result in a draw on especially N from the substrate solution (Jackson et al., 2009). On the other hand, annual vinca grown in pine bark and container substrates composed of processed whole pine trees did not show any statistical differences in foliar N, P, K, Ca, Mg between substrates (Fain et al. (2008).
Despite statistical differences, there was also no clear pattern of foliar nutrients concentration under different fertilizer treatments nor the factors interaction in tested species (Table 12, 13). Hicklenton and Cairns (1992) noticed that when growing cotoneaster and juniper, fertilizer rate had a stronger and more consistent effect on tissue concentration of N, P, and K than fertilizer type. In own research *Aster* and *Spiraea* had the highest NO_3- and K, and *Spiraea* also P, when grown with the amendment of both Basacote and YaraMila.

1.6 Substrate analyses

Substrates from both *Aster* (Table 14) and *Spiraea* (Table 15) had the lowest pH in peatmoss that was higher in substrates containing miscanthus straw and reached 7.6 in *Aster* grown in 70% miscanthus, and 7.2 in *Spiraea* in 50% miscanthus. These findings are confirmed by Evans et al. (2011), where peat had lower pH than all tested rice hulls substrates and Fain et al. (2008), who found that pH was higher for *WholeTree* substrates and decreased with addition of peatmoss to have the lowest value in peatmoss itself. As observed by Altland (2010), in general substrates made from bioenergy crops have pH values higher than recommended.

The highest EC values of substrates from both *Aster* (Table 14) and *Spiraea* (Table 15) were the highest in peatmoss and significantly lower in substrates containing miscanthus straw. Results obtained by Ozdemir et al. (2017) also show that peat had the highest EC in comparison to other tested materials: corn harvest, hazelnut husk, rice hulls, and sawdust. EC in peatmoss substrate in *Aster* was almost double in compare to the same media *Spiraea* and showed a tendency to be higher in *Aster* than in *Spiraea.* Similar results were found by Hicklenton and Cairns (1992), where EC of juniper container leachate was higher than in cotoneaster, which can suggest that available nutrients were not absorbed as readily by juniper. The highest EC was found in substrates of both species in Basacote+YaraMila fertilization, and the lowest in Basacote. YaraMila as easy soluble fertilizer was delivering greater amounts of soluble salts and with simultaneous use of Basacote provided the highest concentrations affecting EC values to rise, while slow releasing Basacote was providing smaller amounts of soluble salts more steadily, thus the EC from this substrate was the lowest.

Total N and NO_3- in substrates of both *Aster* (Table 16) and *Spiraea* (Table 17) was generally higher in peat and was decreasing with the increase of miscanthus in the substrate mixes, which suggests nitrogen immobilization in miscanthus straw. P and K were the highest in *Spiraeae* in 100% miscanthus straw substrate. Similar findings were made by Mustafa et al. (2016) on wheat straw compost contributing amounts of P and K to substrate mixes similar to the leguminous compost. Also Frangi et al. (2012) noted that P and K content increased when *Arundo donax* and *Miscanthus sinensis* rate in the medium was higher. Concentrations of Ca and Mg, that were the highest in peatmoss substrate in *Aster* and decrease with the increase of miscanthus straw, can be related to lime used to deacidify peatmoss: the lowest volume of peatmoss in the substrate mix, the lowest amount of lime. In both species, the lowest macronutrient levels (except for P and K in *Spiraea*) was noted in 100% miscanthus straw substrate and can be related to the low water holding capacity of this medium that did not provide sufficient moisture for releasing nutrients from the fertilizers. In general, the highest concentrations of nutrients in substrates of both species, similar as the highest EC, was noted in Basacote+YaraMila fertilization as the effect of releasing soluble salts from two fertilizer sources, and the lowest nutrient concentrations were generally in the slow released fertilizer Basacote.

Conclusions

Results shown in this research suggest that substrates containing 100% miscanthus straw with applied fertilizer treatments do not provide a sufficient environment fothe r proper growth and development of tested species. Howevthe er, miscanthus amendment to peatmoss shows the potential of being sufficient to partially substitute peat in soilless growing media. Further research is needed on irrigation and fertilization practices, as well miscanthus straw fraction used in container production, to bring physical and chemical parameters of this raw material to values closer to recommended for soilless growing media.

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Table 1. Selected biometric features of *Aster dumosus* 'Jenny' grown in containers with five different substrates (A) composed of various combination of peatmoss (P) and miscanthus straw (M), along with one of three fertilizers (B) including either Basacote (15-11-13) or water soluble YaraMila Complex (12-5-15) either alone or in combination. Different lower case letters within mean A, mean B and AxB interaction indicate statistically significant differences at the significance level ($p < 0.05$) by Fisher's test

Substrate	Fertilization			
	Basacote	Basacote + YaraMila	YaraMila	Mean A
	Height (cm)			
100% P	32.0c	38.2a	34.7b	35.0a
70%P + 30%M	32.1c	32.5c	29.6d	31.4b
50%P + 50%M	20.6fg	23.8e	23.8e	22.7c
30%P + 70%M	18.0i	22.7e	19.7gh	20.1d
100%M	16.5j	21.1f	19.3h	19.0e
Mean B	23.9c	27.7a	25.4b	
	Diameter (cm)			
100% P	27.4c	34.3a	29.5b	30.4a
70%P + 30%M	21.8de	28.8b	22.5d	24.4b
50%P + 50%M	16.3h	21.1ef	20.7ef	19.4c
30%P + 70%M	14.3ij	20.8f	16.5gh	17.2d
100%M	13.3j	17.5g	14.9i	15.3e
Mean B	18.6c	24.5a	20.8b	
	Main shoot number			
100% P	5.6a	4.4b	2.9fg	4.3a
70%P + 30%M	2.1g	4.5b	3.7d	3.5c
50%P + 50%M	3.2e	4.3bc	4.1cd	3.8b
30%P + 70%M	1.6h	2.4fg	2.6f	2.2e
100%M	2.3g	3.2e	2.6f	2.7d
Mean B	3.0c	3.6a	3.2b	
	Main shoot length (cm)			
100% P	27.6bc	34.3a	27.7b	29.8a
70%P + 30%M	28.6b	29.4b	26.9c	28.3b
50%P + 50%M	18.1	21.6d	20.8d	20.2c
30%P + 70%M	14.8g	19.6de	19.0e	17.8d
100%M	14.7g	19.2e	17.3f	17.1e
Mean B	20.8c	24.8a	22.3b	
	Side shoot number			
100% P	37.5b	38.2b	42.9a	39.5a
70%P + 30%M	18.7f	43.1a	29.2d	30.3b
50%P + 50%M	16.9g	33.0c	25.8e	25.2c
30%P + 70%M	5.6k	13.3i	12.9i	10.6e
100%M	7.9j	25.0e	14.6h	15.8d
Mean B	17.3c	30.5a	25.1b	

Table 2. Selected biometric features of *Spiraea densiflora* grown in containers with five different substrates (A) composed of various combination of peatmoss (P) and miscanthus straw (M), along with one of three fertilizers (B) including either Basacote (15-11-13) or water soluble YaraMila Complex (12-5-15) either alone or in combination. Different lower case letters within mean A, mean B and AxB interaction indicate statistically significant differences at the significance level ($p < 0.05$) by Fisher's test

Substrate	Fertilization			
	Basacote	Basacote + YaraMila	YaraMila	Mean A
	Height (cm)			
100% P	16.5c	18.1a	14.9de	16.5a
70%P + 30%M	16.5c	16.7bc	13.fg	15.4b
50%P + 50%M	17.4ab	14.8ef	14.0f	15.4b
30%P + 70%M	15.6d	15.6d	11.7i	14.3c
100%M	12.h	15.0de	13.1gh	13.5d
Mean B	15.7a	15.7a	13.5b	
	Diameter (cm)			
100% P	28.8b	32.9a	21.ef	27.7a
70%P + 30%M	26.0c	26.3c	16.4i	22.5b
50%P + 50%M	21.8e	26.4c	19.8g	22.7b
30%P + 70%M	18.6h	24.6d	17.0i	20.1c
100%M	16.7i	24.0d	20.0fg	20.3c
Mean B	22.4b	26.9a	18.9c	
	Main shoot number			
100% P	2.6b	2.7a	1.3ef	2.2a
70%P + 30%M	1.7c	1.6d	1.0h	1.4b
50%P + 50%M	1.2g	1.4e	1.2g	1.3c
30%P + 70%M	1.2g	1.1h	1.0h	1.1d
100%M	1h	1.3ef	1.2g	1.2c
Mean B	1.5b	1.6a	1.1c	
	Main shoot length (cm)			
100% P	15.8cde	18.5a	14.9fg	16.4a
70%P + 30%M	16.5bc	18.0a	13.3h	15.7b
50%P + 50%M	17.1b	16.2cde	14.5g	15.9b
30%P + 70%M	15.6ef	16.4bcd	10.5j	14.2c
100%M	12.8h	15.7de	12.0i	13.5d
Mean B	15.6b	16.9a	13.0c	
	Number of side shoots (total)			
100% P	10.0b	12.0a	7.5d	10.2a
70%P + 30%M	8.0c	8.4c	4.5h	6.8b
50%P + 50%M	5.7f	6.5e	4.7gh	5.7c
30%P + 70%M	4.4h	6.0f	3.4i	4.6e
100%M	4.6h	5.9f	5.0g	5.1d
Mean B	6.7b	7.7a	5.0c	

Table 3. Selected biometric leaf features of *Aster dumosus* grown in containers with five different substrates (A) composed of various combination of peatmoss (P) and miscanthus straw (M), along with one of three fertilizers (B) including either Basacote (15-11-13) or water soluble YaraMila Complex (12-5-15) either alone or in combination. Different lower case letters within mean A, mean B and AxB interaction indicate statistically significant differences at the significance level ($p < 0.05$) by Fisher's test

Substrate	Fertilization			
	Basacote	Basacote + YaraMila	YaraMila	Mean A
	Leaves number (total)			
100% P	546.7c	772.0b	831.7a	716.8a
70%P + 30%M	309.0e	448.7d	269.4f	342.3b
50%P + 50%M	171.3i	543.0c	194.3h	302.9c
30%P + 70%M	101.0k	145.7j	177.3hi	141.3e
100%M	146.3j	244.7g	189.7h	193.6d
Mean B	254.9c	430.8a	332.5b	
	Leaf blade length (cm)			
100% P	5.73a	5.16b	4.85c	5.2a
70%P + 30%M	5.16b	4.66cd	4.47d	4.8b
50%P + 50%M	3.99f	4.18e	4.28e	4.2d
30%P + 70%M	3.99f	4.32de	4.74c	4.3c
100%M	3.69g	3.87fg	3.86fg	3.8e
Mean B	4.51a	4.44b	4.44b	
	Leaf blade width (cm)			
100% P	1.16a	1.03b	0.99bc	1.06a
70%P + 30%M	1.04b	1.04b	0.93ef	1.00b
50%P + 50%M	0.85g	0.95cde	0.93ef	0.96c
30%P + 70%M	0.89fg	0.96cd	1.05b	0.91d
100%M	0.87g	0.90ef	0.92ef	0.90e
Mean B	0.96a	0.98a	0.97a	
	Leaf blade area (cm^2)			
100% P	4.80a	3.83cd	3.57e	4.01a
70%P + 30%M	4.00b	3.80d	3.13f	3.64b
50%P + 50%M	2.53i	3.00fg	2.93gh	3.21c
30%P + 70%M	2.57i	3.10f	3.97bc	2.82d
100%M	2.30j	2.80h	2.60i	2.57e
Mean B	3.24b	3.31a	3.24b	

Table 4. Selected biometric leaf features of *Spiraea densiflora* grown in containers with five different substrates (A) composed of various combination of peatmoss (P) and miscanthus straw (M), along with one of three fertilizers (B) including either Basacote (15-11-13) or water soluble YaraMila Complex (12-5-15) either alone or in combination. Different lower case letters within mean A, mean B and AxB interaction indicate statistically significant differences at the significance level ($p < 0.05$) by Fisher's test

Substrate	Fertilization			
	Basacote	Basacote + YaraMila	YaraMila	Mean A
	Leaves number			
100% P	226d	311c	130j	222c
70%P + 30%M	205e	446a	167h	251a
50%P + 50%M	189f	354b	178g	240b
30%P + 70%M	140i	233d	64l	146d
100%M	127j	205e	10k	146d
Mean B	177b	300a	129c	
	Leaf blade length (cm)			
100% P	4.37c	4.83a	4.13d	4.44a
70%P + 30%M	3.07g	4.60b	3.03g	3.44c
50%P + 50%M	2.97gh	4.70ab	4.70ab	4.12b
30%P + 70%M	2.77h	3.50f	2.90gh	3.06d
100%M	3.00g	3.73e	3.57ef	3.43c
Mean B	3.23c	4.25a	3.67b	
	Leaf blade width (cm)			
100% P	3.16c	3.47b	3.07c	3.24a
70%P + 30%M	2.51g	2.67e	2.20i	2.43c
50%P + 50%M	2.27i	3.68a	2.55fg	2.83b
30%P + 70%M	2.63ef	2.71e	2.03j	2.45c
100%M	1.97j	2.85d	2.39h	2.40c
Mean B	2.51b	3.10a	2.45c	
	Leaf blade area (cm^2)			
100% P	9.83c	11.77b	8.23e	9.94a
70%P + 30%M	4.17l	8.75d	4.67k	5.50e
50%P + 50%M	5.70i	12.37a	8.83d	8.97b
30%P + 70%M	5.30j	6.87g	7.77f	6.64d
100%M	8.87d	7.70f	6.13h	7.57c
Mean B	6.77c	9.54a	7.13b	

Table 4. Flowering of *Aster dumosus* grown in containers with five different substrates (A) composed of various combination of peatmoss (P) and miscanthus straw (M), along with one of three fertilizers (B) including either Basacote (15-11-13) or water soluble YaraMila Complex (12-5-15) either alone or in combination. Different lower case letters within mean A, mean B and AxB interaction indicate statistically significant differences at the significance level ($p < 0.05$) by Fisher's test

Substrate	Fertilization			
	Basacote	Basacote + YaraMila	YaraMila	Mean A
	Flower number (average per plant)			
100% P	23.2b	9.7f	10.3e	14.4b
70%P + 30%M	24.4a	17.2c	4.8j	15.5a
50%P + 50%M	8.3g	8.8g	4.3j	7.1e
30%P + 70%M	7.3h	10.3e	9.5f	9.1c
100%M	3.6k	12.4d	5.7i	7.3d
Mean B	13.4a	11.7b	6.9c	
	Flower diameter (cm)			
100% P	4.2ab	4.1abcd	4.2ab	4.2a
70%P + 30%M	4.1abcd	4.2ab	4.0bc	4.1a
50%P + 50%M	3.8de	4.3a	4.2a	4.1a
30%P + 70%M	3.9cd	4.0bcd	4.0bcd	4.0cb
100%M	3.9cd	4.0bcd	3.8de	3.9c
Mean B	4.0b	4.1a	4.0b	
	% of flowering plants			
100% P	100a	100a	100a	100a
70%P + 30%M	100a	100a	100a	100a
50%P + 50%M	81c	92b	91b	88b
30%P + 70%M	40e	48d	48d	45c
100%M	25g	35f	36ef	32d
Mean B	69b	75a	75a	

Table 6. Fresh and dry biomass of *Aster dumosus* grown in containers with five different substrates (A) composed of various combination of peatmoss (P) and miscanthus straw (M), along with one of three fertilizers (B) including either Basacote (15-11-13) or water soluble YaraMila Complex (12-5-15) either alone or in combination. Different lower case letters within mean A, mean B and AxB interaction indicate statistically significant differences at the significance level ($p < 0.05$) by Fisher's test

Substrate	Fertilization			
	Basacote	Basacote + YaraMila	YaraMila	Mean A
	Aboveground fresh weight (g)			
100% P	90.01d	173.78a	125.07b	129.6a
70%P + 30%M	75.13f	104.79c	67.44g	82.5b
50%P + 50%M	46.65j	85.35e	63.14h	65.1c
30%P + 70%M	18.43l	49.03j	40.35k	35.9d
100%M	18.05l	55.10i	18.84l	30.7e
Mean B	49.65c	93.61a	62.96b	
	Root fresh weight (g)			
100% P	21.13fg	30.60a	20.50g	24.1a
70%P + 30%M	23.82de	23.05e	20.47g	22.4c
50%P + 50%M	19.02h	25.58c	24.24d	22.9b
30%P + 70%M	15.09i	19.76gh	21.47f	18.8d
100%M	12.94k	27.69c	14.11j	18.3e
Mean B	18.4c	25.33a	20.16b	
	Aboveground dry weight (g)			
100% P	16.72e	37.98a	22.94c	25.9a
70%P + 30%M	13.24g	34.31b	15.01f	20.9b
50%P + 50%M	6.65i	21.28d	12.81g	13.6c
30%P + 70%M	2.17k	9.30h	7.34i	6.3d
100%M	2.26k	10.01h	3.43j	5.2e
Mean B	8.21c	22.58a	12.31b	
	Root dry weight (g)			
100% P	3.37g	6.45b	4.63d	4.8a
70%P + 30%M	2.94h	7.37a	3.86f	4.7a
50%P + 50%M	2.47i	5.68c	4.37e	4.2b
30%P + 70%M	1.30j	3.02h	3.37g	2.6c
100%M	1.23j	4.39e	2.44i	2.7c
Mean B	2.26c	5.38a	3.73b	

Table 7. Fresh and dry biomass of *Spiraea densiflora* grown in containers with five different substrates (A) composed of various combination of peatmoss (P) and miscanthus straw (M), along with one of three fertilizers (B) including either Basacote (15-11-13) or water soluble YaraMila Complex (12-5-15) either alone or in combination. Different lower case letters within mean A, mean B and AxB interaction indicate statistically significant differences at the significance level ($p < 0.05$) by Fisher's test

Substrate	Fertilization			
	Basacote	Basacote + YaraMila	YaraMila	Mean A
	Aboveground fresh weight (g)			
100% P	58.53b	61.20a	51.43c	57.06a
70%P + 30%M	43.83e	36.50g	44.93d	42.34b
50%P + 50%M	40.83f	33.87h	32.52hj	35.74c
30%P + 70%M	24.70l	31.73j	29.07k	28.50e
100%M	29.60k	39.33f	21.93l	30.29d
Mean B	39.30b	40.81a	35.98c	
	Root fresh weight (g)			
100% P	35.20b	37.17a	27.50c	33.29a
70%P + 30%M	26.33de	25.25fe	34.93b	29.29b
50%P + 50%M	22.60g	15.37i	24.80f	20.92c
30%P + 70%M	22.60g	25.20ef	12.67k	20.16d
100%M	17.50h	26.53cd	13.97j	19.33e
Mean B	24.85b	25.95a	22.77c	
	Aboveground dry weight (g)			
100% P	37.16a	32.80b	30.76c	33.57a
70%P + 30%M	27.11d	25.14e	33.76b	29.11b
50%P + 50%M	31.53c	25.36e	23.89f	26.93c
30%P + 70%M	17.15i	23.19f	18.08hi	19.47d
100%M	18.48h	21.37g	9.89j	16.58e
Mean B	26.28a	25.60b	23.28c	
	Root dry weight (g)			
100% P	21.43a	21.14a	17.92b	20.16a
70%P + 30%M	14.29c	14.44c	17.48b	15.52b
50%P + 50%M	14.44c	10.73f	14.94c	13.37c
30%P + 70%M	10.04g	12.22e	8.21h	10.16d
100%M	8.38h	13.13d	6.54i	9.35e
Mean B	13.71b	14.32a	13.02c	

Table 8. Leaf color of *Aster dumosus* grown in containers with five different substrates (A) composed of various combination of peatmoss (P) and miscanthus straw (M), along with one of three fertilizers (B) including either Basacote (15-11-13) or water soluble YaraMila Complex (12-5-15) either alone or in combination. Different lower case letters within mean A, mean B and AxB interaction indicate statistically significant differences at the significance level ($p < 0.05$) by Fisher's test

Substrate	Fertilization			
	Basacote	Basacote + YaraMila	YaraMila	Mean A
100% P				
70%P + 30%M				
50%P + 50%M				
30%P + 70%M				
100%M				
Mean B				

Table 9. Leaf color of *Spiraea densiflora* grown in containers with five different substrates (A) composed of various combination of peatmoss (P) and miscanthus straw (M), along with one of three fertilizers (B) including either Basacote (15-11-13) or water soluble YaraMila Complex (12-5-15) either alone or in combination. Different lower case letters within mean A, mean B and AxB interaction indicate statistically significant differences at the significance level ($p < 0.05$) by Fisher's test

Substrate	Fertilization			
	Basacote	Basacote + YaraMila	YaraMila	Mean A
100% P				
70%P + 30%M				
50%P + 50%M				
30%P + 70%M				
100%M				
Mean B				

Table 10. Chlorophyll contents in leaves of *Aster dumosus* grown in containers with five different substrates (A) composed of various combination of peatmoss (P) and miscanthus straw (M), along with one of three fertilizers (B) including either Basacote (15-11-13) or water soluble YaraMila Complex (12-5-15) either alone or in combination. Different lower case letters within mean A, mean B and AxB interaction indicate statistically significant differences at the significance level ($p < 0.05$) by Fisher's test

Substrate	Fertilization			
	Basacote	Basacote + YaraMila	YaraMila	Mean A
	Chlorophyll a (mg/g)			
100% P	0.626ef	0.908a	0.716d	0.750a
70%P + 30%M	0.579gh	0.783c	0.580g	0.647c
50%P + 50%M	0.497j	0.791bc	0.821b	0.703b
30%P + 70%M	0.343k	0.542hi	0.531ij	0.472d
100%M	0.603fg	0.649e	0.690d	0.647c
Mean B	0.529c	0.735a	0.668b	
	Chlorophyll b (mg/g)			
100% P	0.455b	0.530a	0.383d	0.456a
70%P + 30%M	0.376d	0.425c	0.330ef	0.377b
50%P + 50%M	0.317f	0.383d	0.427c	0.376b
30%P + 70%M	0.242i	0.268g	0.297g	0.269d
100%M	0.320f	0.344e	0.346e	0.337c
Mean B	0.342c	0.390a	0.357b	
	Total chlorophyll (mg/g)			
100% P	1.081d	1.438a	1.099d	1.206a
70%P + 30%M	0.955fg	1.208c	0.910h	1.024c
50%P + 50%M	0.814i	1.174c	1.249b	1.079b
30%P + 70%M	0.585j	0.810i	0.829i	0.741e
100%M	0.923gh	0.993f	1.036e	0.984d
Mean B	0.872c	1.125a	1.024b	

Table 11. Chlorophyll contents in leaves of *Spiraea densiflora* grown in containers with five different substrates (A) composed of various combination of peatmoss (P) and miscanthus straw (M), along with one of three fertilizers (B) including either Basacote (15-11-13) or water soluble YaraMila Complex (12-5-15) either alone or in combination. Different lower case letters within mean A, mean B and AxB interaction indicate statistically significant differences at the significance level ($p < 0.05$) by Fisher's test

Substrate	Fertilization			
	Basacote	Basacote + YaraMila	YaraMila	Mean A
	Chlorophyll a			
100% P	0.999b	1.159a	0.833d	0.997a
70%P + 30%M	0.576f	0.789d	0.628e	0.648d
50%P + 50%M	0.800d	0.900c	1.003b	0.901b
30%P + 70%M	0.963b	0.881c	0.802d	0.882b
100%M	0.822d	0.918c	0.663e	0.801c
Mean B	0.832b	0.939a	0.786c	
	Chlorophyll b			
100% P	0.536b	0.633a	0.397g	0.522a
70%P + 30%M	0.326i	0.413efg	0.372h	0.365e
50%P + 50%M	0.403fg	0.452d	0.497c	0.451b
30%P + 70%M	0.497c	0.433de	0.390gh	0.440c
100%M	0.426ef	0.523b	0.244j	0.398d
Mean B	0.438b	0.496a	0.380c	
	Total chlorophyll			
100% P	1.535b	1.791a	1.230fg	1.519a
70%P + 30%M	0.902h	1.202ef	0.999g	1.013e
50%P + 50%M	1.204ef	1.353e	1.500bc	1.352b
30%P + 70%M	1.460cd	1.314e	1.192f	1.322c
100%M	1.248f	1.441d	0.906h	1.198d
Mean B	1.270b	1.436a	1.166c	

Table 12. Foliar nutrient contents in *Aster dumosus* grown in containers with five different substrates (A) composed of various combination of peatmoss (P) and miscanthus straw (M), along with one of three fertilizers (B) including either Basacote (15-11-13) or water soluble YaraMila Complex (12-5-15) either alone or in combination. Different lower case letters within mean A, mean B and AxB interaction indicate statistically significant differences at the significance level ($p < 0.05$) by Fisher's test

Substrate	Fertilization			
	Basacote	Basacote + YaraMila	YaraMila	Mean A
	$N\text{-}NO_3^-$ (mg/g)			
100% P	10.0ef	12.1b	13.3a	11.8a
70%P + 30%M	9.8fg	11.4c	10.7d	10.7b
50%P + 50%M	9.5fgh	10.6d	10.6d	10.2c
30%P + 70%M	10.5de	9.2hi	9.4gh	9.7d
100%M	9.8fg	10.4de	8.8i	9.6d
Mean B	10.0b	10.8a	10.6a	
	P (mg/100g)			
100% P	117gh	184c	72i	124d
70%P + 30%M	182c	167d	139f	163b
50%P + 50%M	189c	188c	126g	168b
30%P + 70%M	213b	120gh	114gh	149c
100%M	304a	152e	143ef	200a
Mean B	201a	162b	119c	
	K (mg/100g)			
100% P	2667fg	4058b	4367a	3697a
70%P + 30%M	3117e	3925c	3208de	3417b
50%P + 50%M	2692f	3308d	3200de	3067c
30%P + 70%M	2558gh	2467hi	2417i	2481e
100%M	2417i	2750f	2675fg	2614d
Mean B	2690c	3302a	3173b	
	Ca (mg/100g)			
100% P	1883b	1475hi	1558efg	1639b
70%P + 30%M	1558efg	1592efg	1333j	1494c
50%P + 50%M	1708d	1792c	1633e	1711a
30%P + 70%M	2042a	1450i	1542fgh	1678a
100%M	1517ghi	1625ef	1242k	1461d
Mean B	1742a	1587b	1462c	
	Mg (mg/100g)			
100% P	159g	242c	214de	205c
70%P + 30%M	175f	244c	208e	209c
50%P + 50%M	220d	238c	242c	233b
30%P + 70%M	282a	213de	261b	252a
100%M	269b	244c	186f	233b
Mean B	221b	236a	222b	

Table 13. Foliar nutrient contents in *Spiraea densiflora* grown in containers with five different substrates (A) composed of various combination of peatmoss (P) and miscanthus straw (M), along with one of three fertilizers (B) including either Basacote (15-11-13) or water soluble YaraMila Complex (12-5-15) either alone or in combination. Different lower case letters within mean A, mean B and AxB interaction indicate statistically significant differences at the significance level ($p < 0.05$) by Fisher's test

Substrate	Fertilization			
	Basacote	Basacote + YaraMila	YaraMila	Mean A
	$N\text{-}NO_3^-$(mg/g)			
100% P	10.5cd	12.3a	10.6c	11.0a
70%P + 30%M	9.4f	11.3b	10.de	10.1b
50%P + 50%M	9.6ef	9.1fgh	9.1fgh	9.2c
30%P + 70%M	9.2fg	9.ghi	8.7ghij	9.0d
100%M	8.4j	8.5ij	8.6hij	8.5e
Mean B	9.4b	9.9a	9.4b	
	P (mg/100g)			
100% P	329f	652c	898a	627a
70%P + 30%M	256i	710b	448e	442c
50%P + 50%M	163k	394f	222j	260e
30%P + 70%M	201j	344g	299h	281d
100%M	465de	452e	493d	470b
Mean B	283c	496a	472b	
	K (mg/100g)			
100% P	2033bc	1992bcd	2333a	2119a
70%P + 30%M	1791e	2087b	1983cd	1938b
50%P + 50%M	1633f	2033bc	1608f	1758c
30%P + 70%M	1600f	1908d	1667f	1725c
100%M	1267h	1617f	1500g	1461d
Mean B	1665c	1616a	1818b	
	Ca (mg/100g)			
100% P	1675c	1242hi	1333g	1417d
70%P + 30%M	1600d	1800b	1467ef	1600b
50%P + 50%M	2025a	1300gh	1608cd	1644a
30%P + 70%M	1633cd	1508e	1425f	1522c
100%M	1517e	1208i	1208i	1311e
Mean B	1690a	1384b	1408b	
	Mg (mg/100g)			
100% P	254fg	337b	267ef	286d
70%P + 30%M	241g	263ef	327bc	279e
50%P + 50%M	334b	270e	303d	302c
30%P + 70%M	339b	303d	303d	315b
100%M	373a	316cd	306d	332a
Mean B	308a	300b	301b	

Table 14. pH and EC of substrates in *Aster dumosus* grown in containers with five different substrates (A) composed of various combination of peatmoss (P) and miscanthus straw (M), along with one of three fertilizers (B) including either Basacote (15-11-13) or water soluble YaraMila Complex (12-5-15) either alone or in combination. Different lower case letters within mean A, mean B and AxB interaction indicate statistically significant differences at the significance level ($p < 0.05$) by Fisher's test

Substrate	Fertilization			
	Basacote	Basacote + YaraMila	YaraMila	Mean A
	pH			
100% P	7.2cde	7.1de	7.0e	7.1b
70%P + 30%M	7.4bc	7.4bc	7.6ab	7.4ab
50%P + 50%M	7.3cd	7.6ab	7.6ab	7.5ab
30%P + 70%M	7.7a	7.4bc	7.6ab	7.6a
100%M	7.6ab	7.3cd	7.3cd	7.4ab
Mean B	7.4a	7.3a	7.4a	
	EC (µS/cm)			
100% P	656d	1107a	794b	852a
70%P + 30%M	510f	715c	545ef	590c
50%P + 50%M	438g	820b	652d	636b
30%P + 70%M	375h	571e	534f	494d
100%M	255j	305i	323i	294e
Mean B	447c	703a	570b	

Table 15. pH and EC of substrates in *Spiraea densiflora* grown in containers with five different substrates (A) composed of various combination of peatmoss (P) and miscanthus straw (M), along with one of three fertilizers (B) including either Basacote (15-11-13) or water soluble YaraMila Complex (12-5-15) either alone or in combination. Different lower case letters within mean A, mean B and AxB interaction indicate statistically significant differences at the significance level ($p < 0.05$) by Fisher's test

Substrate	Fertilization			
	Basacote	Basacote + YaraMila	YaraMila	Mean A
	pH			
100% P	6.7f	5.6i	6.2h	6.1d
70%P + 30%M	6.9cde	6.2h	6.9cde	6.7c
50%P + 50%M	7.0bcd	7.1bcd	7.4a	7.2a
30%P + 70%M	7.3ab	6.5fg	7.2abc	7.0b
100%M	7.1bcd	6.5fg	6.5fg	6.7c
Mean B	7.0a	6.4c	6.8b	
	EC (µS/cm)			
100% P	410d	604a	425cd	480a
70%P + 30%M	336f	602a	437c	440b
50%P + 50%M	288gh	371e	267i	309e
30%P + 70%M	272hi	475b	225j	324d
100%M	306g	485b	339f	377c
Mean B	322c	500a	339b	

Table 16. Substrate nutrient contents in *Aster dumosus* grown in containers with five different substrates (A) composed of various combination of peatmoss (P) and miscanthus straw (M), along with one of three fertilizers (B) including either Basacote (15-11-13) or water soluble YaraMila Complex (12-5-15) either alone or in combination. Different lower case letters within mean A, mean B and AxB interaction indicate statistically significant differences at the significance level ($p < 0.05$) by Fisher's test

Substrate	Fertilization			
	Basacote	Basacote + YaraMila	YaraMila	Mean A
	N total (% d.w.)			
100% P	2.5i	4.2a	3.7cd	3.5a
70%P + 30%M	2.1j	4.0b	3.5e	3.2b
50%P + 50%M	1.9k	3.8c	3.4f	3.0c
30%P + 70%M	1.9k	3.8c	3.2g	3.0c
100%M	1.8l	3.6de	3.1h	2.8d
Mean B	2.0c	3.9a	3.4b	

	NO_3 (mg/dm^3)			
100% P	18.9ef	17.2gh	16.6h	17.5d
70%P + 30%M	20.1d	20.3d	19.3de	19.9c
50%P + 50%M	21.7c	25.9a	23.8b	23.8a
30%P + 70%M	23.4b	23.5b	18.1fg	21.7b
100%M	7.7i	5.5j	7.5i	6.9e
Mean B	18.4a	18.5a	17.1b	
	P (mg/dm^3)			
100% P	16k	56e	21j	64a
70%P + 30%M	30h	57e	43g	43d
50%P + 50%M	24i	63c	60d	49c
30%P + 70%M	11l	80b	63c	52b
100%M	30h	49f	112a	31e
Mean B	22c	61a	59b	
	K (mg/ dm^3)			
100% P	60c	60c	40e	53c
70%P + 30%M	40e	70b	80a	63a
50%P + 50%M	40e	80a	60c	60b
30%P + 70%M	30f	50d	40e	40d
100%M	30f	30f	20g	27e
Mean B	40c	58a	48b	
	Ca (mg/dm^3)			
100% P	1692a	1342cd	1275f	1436a
70%P + 30%M	1367bc	1333def	1300ef	1333c
50%P + 50%M	1367bc	1633a	1367bc	1456a
30%P + 70%M	1325def	1425b	1417b	1389b
100%M	658g	442i	542h	547d
Mean B	1282a	1235b	1180c	
	Mg (mg/dm^3)			
100% P	128d	149b	152b	143a
70%P + 30%M	125de	136c	158a	140b
50%P + 50%M	115f	129d	120ef	121c
30%P + 70%M	109g	117f	109g	112d
100%M	57j	68h	67h	64e
Mean B	107b	119a	121a	

Table 17. Substrate nutrient contents in *Spiraea densiflora* grown in containers with five different substrates (A) composed of various combination of peatmoss (P) and miscanthus straw (M), along with one of three fertilizers (B) including either Basacote (15-11-13) or water soluble YaraMila Complex (12-5-15) either alone or in combination. Different lower case letters within mean A, mean B and AxB interaction indicate statistically significant differences at the significance level ($p < 0.05$) by Fisher's test

Substrate	Fertilization			
	Basacote	Basacote + YaraMila	YaraMila	Mean A
	N total (% d.w.)			
100% P	1.62e	2.70a	2.55ab	2.29a
70%P + 30%M	1.47ef	2.56ab	2.49abc	2.12b
50%P + 50%M	1.39ef	2.40bcd	2.31bcd	2.03b
30%P + 70%M	1.30f	2.31bcd	2.30bcd	1.97b
100%M	1.54ef	2.25cd	2.18d	1.99b
Mean B	1.47b	2.43a	2.37a	
	NO_3 (mg/dm^3)			
100% P	18.2e	51.0a	15.1g	28.1a
70%P + 30%M	17.0f	36.1b	18.1ef	22.2b
50%P + 50%M	22.6c	19.7d	22.0c	21.4c
30%P + 70%M	19.0de	13.9h	13.5h	15.5d
100%M	5.8i	6.0i	5.8i	5.9e
Mean B	16.5b	24.6a	14.9c	
	P (mg/dm^3)			
100% P	44h	48g	123b	72c
70%P + 30%M	48gh	121bc	117c	92b
50%P + 50%M	37i	50g	87e	58e
30%P + 70%M	25j	78f	103d	69d
100%M	81f	148a	149a	126a
Mean B	46c	87b	116a	
	K (mg/dm^3)			
100% P	70e	110d	80g	87d
70%P + 30%M	100e	140c	90f	106b
50%P + 50%M	90f	150b	60h	100c
30%P + 70%M	60h	140c	60h	87d
100%M	80g	180a	100e	120a
Mean B	80b	144a	78b	
	Ca (mg/dm^3)			
100% P	1077d	857hi	907gh	947c
70%P + 30%M	947fg	1020de	1177c	1051b
50%P + 50%M	1237ab	1200bc	1267a	1234a
30%P + 70%M	967ef	840i	933fg	913d
100%M	563j	547j	430k	513e
Mean B	955a	887b	943a	

	Mg (mg/dm^3)			
100% P	82ef	85e	82ef	83c
70%P + 30%M	94d	121a	109b	106a
50%P + 50%M	96d	103c	79f	93b
30%P + 70%M	82ef	109b	82ef	91b
100%M	57gh	55h	60g	58d
Mean B	82b	93a	83b	

4. Opis wyników i dyskusja

4.1. pH, zasolenie i zawartość wybranych pierwiastków w podłożach

Wartości pH u większości badanych gatunków (tawuła str. 98, aster str. 99, rudbekia str. 54 i rozchodnik str. 27) wykazywały tendencję wzrostową wraz ze wzrostem zawartości słomy miskanta w podłożu. Wyjątkiem były hortensja (str. 27) i żywotnik (str. 55), u których najwyższe pH odnotowano w podłożu 100% torfu, a jego wartości osiągnęły odpowiednio 8,0 i 7,4. Jak zauważył Altland (2010), podłoża na bazie roślin energetycznych zazwyczaj wykazują wartości wyższe od zalecanych w produkcji pojemnikowej. Podobnie w badaniach Evans'a i in. (2011) podłoża na bazie łusek ryżowych miały wyższe pH w porównaniu do podłoża torfowego, a w badaniach Fain'a i in. (2008) podłoże *WholeTree* stworzone na bazie rozdrobionych drzew sosnowych również miało najwyższe pH, którego wartości malały wraz ze wzrostem zawartości torfu w podłożach. Wyniki te sugerują, że ogólnie materiały lignocelulozowe mają wyższe pH w porównaniu do substratu torfowego. Wartym zanotowania jest, że pomimo zastosowania mieszanek podłożowych o pH początkowym na poziomie 6,2-6,5, wartości pH pod koniec sezonu wegetacyjnego kształtowały się w zupełnie różnych zakresach w obrębie każdego gatunku. Najniższy zakres wartości pH odnotowano w podłożach u rozchodnika: 5,8 dla 100% torfu do 6,5 w 100% słomy z miskanta (str. 24) , a najwyższy w podłożach u hortensji: 7,3 w 100% miskancie do 8,0 w 100% torfie (str. 22). Z kolei najwęższy zakres wartości pH odnotowano w podłożach u astra, które kształtowały się na poziomie 7,1-7,6 (str. 83).

Całkowite stężenie soli (EC) w podłożach wykazywało odwrotną tendencję do wartości pH: u wszystkich testowanych gatunków było ono najwyższe w podłożach zawierających 100% torfu i malało wraz ze wzrostem zawartości słomy miskanta w podłożu (str. 27, 54, 55, 91, 92). Podobny trend zanotowano w podłożach na bazie kukurydzy, łupin leszczyny, łusek ryżowych i trocin, które miały mniejsze EC w porównaniu do torfu (Ozdemir i in. 2017). Związane jest to z mniejszą pojemnością wodną tych materiałów i w konsekwencji zwiększonym ryzykiem wypłukiwania pierwiastków, a tym samym zmniejszeniem EC podłoży. Podobnie jak w przypadku pH, również zakresy wartości EC różniły się pomiędzy gatunkami: najniższe było w podłożach u żywotnika 161-321 µS/cm (str. 55), a najwyższe u rozchodnika 402-995 µS/cm (str. 27). Z kolei u rudbekii różnice w EC pomiędzy podłożami były najmniejsze i kształtowały się na poziomie 377-480 µS/cm) (str. 54). Tak zróżnicowane wartości EC pomiędzy gatunkami spowodowane mogą być przede wszystkim fizjologią samych gatunków, co Hinklenton i Cairns (1992) wyjaśnili sugerując, że wyższe wartości EC w podłożach jałowca w porównaniu do wartości EC u irgi spowodowane są wolniejszym wzrostem tego krzewu iglastego, a tym samym mniejszym poborem składników pokarmowych przez ten gatunek.

Zawartości większości pierwiastków w podłożach (str. 28, 29, 56-58, 92-95) korelują z wartościami EC i wykazują tendencję malejącą wraz ze wzrostem zawartości słomy z miskanta w podłożu. Szczególnie widoczne jest to na przykładzie zawartości azotu całkowitego oraz NO_3- w podłożach u astra (str. 92-93), rudbekii (str. 56-57) oraz tawuły (str.94-95); najniższe zawartości odnotowano w podłożu zawierającym 100% miskanta, i stanowiły one w przybliżeniu odpowiednio 40%, 30% i 20% najwyższych zawartości NO_3- w 100% torfie. Jak sugeruje Jackson i in. (2009), wynikać to może z aktywności mikrobiologicznej w miskancie jako materiale lignocelulozowym, co objawia się szczególnie poprzez niższą zawartość azotu w podłożu.

Fosfor i potas wykazały z kolei trend odwrotny do azotu całkowitego i NO_3-: zawartości tych pierwiastków w podłożach były wyższe w 100% miskancie w porównaniu do 100% torfu. Szczególnie widoczne jest to w podłożach u tawuły (str. 94), rudbekii (str. 56) i żywotnika (str. 57), u których zawartości tych pierwiastków w podłożach z 100% słomy z miskanta były nawet 175% wyższe w porównaniu do wartości stwierdzonych w podłożu zawierającym 100% torfu. Podobną tendencję wykazały podłoża na bazie lasecznicy trzcinowatej i miskanta chińskiego, w których zawartość fosforu i potasu wzrastała wraz ze wzrostem zawartości tych dwóch materiałów w mieszankach podłożowych. Z kolei Mustafa i in. (2016) po przeprowadzeniu badań podłoży na bazie przekompostowanej słomy pszennej wysnuli wnioski, że może ono dostarczać zawartości potasu i fosforu porównywalne do tych z kompostu z roślin motylkowych.

Pomimo zastosowania wapna dolomitowego do odkwaszenia torfu, a tym samym jego malejącej dawki w podłożach wraz ze wzrostem zawartości słomy z miskanta, u żadnego z testowanych gatunków nie zaobserwowano tendencji w kształtowaniu się tych zawartości w zależności od podłoża (28, 29, 56, 58, 92-95). Wyniki te mogą wskazywać na szereg skomplikowanych interakcji pomiędzy roślinami, składnikami podłoży i czynnikami środowiskowymi, a tym samym wykazywać nieścisłości pomiędzy zawartościami pierwiastków w mieszankach podłożowych (Mustafa i in. 2016).

4.2. Barwa liści, zawartość chlorofilu i wybranych pierwiastków w liściach

Zawartość chlorofili oraz jasność i tony barw liści różniły się pomiędzy testowanymi roślinami, co wynika ściśle z ich cech gatunkowych. W obrębie gatunków można zauważyć różnice w tych pomiarach w zależności od mieszanki podłożowej. Najwięcej chlorofili, których zawartość miała tendencję do odzwierciedlenia w najciemniejszej barwie liści, u rudbekii (str. 48-49), tawuły (str. 86,88) i hortensji (str. 24) odnotowano w podłożu ze 100% torfu, u żywotnika (str. 50) w podłożu z 30% dodatkiem słomy z miskanta, u astra (str. 86-87) w podłożach z maksymalnym dodatkiem 50% słomy z miskanta, a u rozchodnika (str. 23) w podłożach 70% i 100% miskanta. Z kolei Fain i in. (2008) nie odnotowali różnic w wartościach SPAD liści petunii w podłożach *WholeTree*, podobnie jak Kuisma i in. (2014) nie odnotowali różnic w zawartości chlorofilu pomiędzy liśćmi truskawki uprawianej w podłożach z włókna kokosowego, torfu, trzciny kanaryjskiej oraz mieszanki torfu z trzciną.

U testowanych gatunków nie stwierdzono jasnych zależności pomiędzy zawartością miskanta w podłożu, a zawartością wybranych pierwiastków w liściach (str. 24- 26, 51-53, 89-90). Nie stwierdzono również korelacji pomiędzy zawartością pierwiastków w podłożach, a ich zawartościami w liściach. Jak wspomniano w poprzednim podrozdziale, tak niejasne wyniki mogą być spowodowane wieloma interakcjami zachodzącymi pomiędzy składnikami podłoży, czynnikami środowiskowymi oraz samymi gatunkami (Mustafa i in.

2016). Pod względem wizualnym, gatunki wykazywały słabsze wybarwienie liści zazwyczaj w podłożach zawierających powyżej 50% słomy z miskanta.

4.3. Pomiary biometryczne roślin

Najwyższe rośliny o największej średnicy u rudbekii (str. 41-42), astra (str. 79), tawuły (str. 80), rozchodnika (str. 18) i hortensji (str. 18-19) zaobserwowano w uprawie w podłożu zawierającym 100% torfu. U wymienionych pięciu gatunków, wysokość i średnica roślin malała wraz ze wzrostem zawartości słomy miskanta w podłożu. Podobne tendencje występowały u pozostałych zmierzonych cech biometrycznych oraz świeżej i suchej biomasy części nadziemnej i korzeni str. 18-21, 41-48, 79-85). Również badania Frangi'ego i in. (2012) wykazały, że laurowiśnia i kalina wawrzynowata charakteryzowały się mniejszym wzrostem w podłożach zawierających 50% i 75% słomy z miskanta. Wynikać to może przede wszystkim z EC podłoży oraz zawartości wybranych pierwiastków w podłożach, których to wartości były najwyższe w 100% torfie i malały wraz ze wzrostem zawartości słomy miskanta w podłożach, ale również z dostępności wody, której niedobór zredukował wzrost testowanych gatunków oraz przyrost biomasy. Jak zauważył bowiem Clemmensen (2004), podłoża z przekompostowanej słomy miskanta olbrzymiego mają mniejszą zdolność retencji wody w porównaniu do torfu, i zgodnie z sugestią Harris'a i in. (2020) dodatek 30% i więcej materiałów lignocelulozowych do podłoży wymaga dostosowania wielkości i częstotliwości nawadniania z uwzględnieniem zmian właściwości fizycznych tych podłoży. Warto jednak zauważyć, że w przypadku wysokości i średnicy, różnica pomiędzy roślinami uprawianymi w 100% torfu w porównaniu do 100% miskanta (najniższe rośliny o największej średnicy) u hortensji (str. 18,19) i astra (str. 79) wynosiła około 40-50%, u rudbekii (str.41-42) ok. 50% dla wysokości i ok. 30% dla średnicy, u rozchodnika (str. 18) 30-40%, a dla tawuły (str. 80) kształtowała się na poziomie 20-30%, co przy różnicy w zakresie wysokości 13,5-16,5 cm nie było jednak wizualnie rozpoznawalne. Największą różnicę w przypadku biomasy zanotowano u astra (str. 84), którego sucha masa części nadziemnej wyprodukowanej w podłożu ze 100% słomy miskanta stanowiła zaledwie 20% masy roślin uprawianych w 100% torfie, oraz u hortensji (str. 23), u której wartość ta wynosiła 25%. W przypadku suchej masy korzeni tych dwóch gatunków oraz suchej masy części nadziemnej i suchej masy korzeni rozchodnika (str. 22), rudbekii (str. 44) i tawuły (str. 85), różnice te kształtowały się na poziomie 40-50%. Z kolei w uprawie żywotnika (str. 45) najwyższe rośliny o największej suchej i świeżej masie pędów oraz suchej masie korzeni, odnotowano w podłożu z 70% zawartością słomy z miskanta, a ich największą średnicę w 100% torfu. W porównaniu do najmniejszych roślin o najmniejszej średnicy i najmniejszej biomasie uprawianych w 100% słomy z miskanta, różnice we wzroście wynosiły 15-22%, natomiast różnice w suchej masie części nadziemnej i korzeni sięgały 50%. Przeprowadzone korelacje nie wykazały jednak związku pomiędzy suchą biomasą roślin, a zawartością poszczególnych pierwiastków w liściach.

Podobnie jak w przypadku pomiarów części wegetatywnych roślin oraz ich suchej biomasy, również wartości parametrów związanych z kwitnieniem bylin były najwyższe w 100% torfie i malały wraz ze wzrostem zawartości słomy z miskanta w podłożu, a rudbekia zupełnie nie wytworzyła kwiatostanów w podłożu z 100% słomy z miskanta (str. 20, 47, 83,). Również Harris i in. (2020) zaobserwowali najmniejszą liczbę kwiatów petunii w podłożach zawierających domieszki rozdrobnionego drewna i włókna drzewnego w porównaniu do mieszanek z włóknem kokosowym. Najdłuższe pędy kwiatostanowe, największą liczbę kwiatostanów o największej średnicy oraz największy procent kwitnących roślin zanotowano u rudbekii uprawianej w 100% torfie oraz w podłożu zawierającym 30% słomy z miskanta (str. 47). Również aster (str. 83) wytworzył najwięcej kwiatostanów i miał największy procent kwitnących roślin w podłożach 100% torf i 30% zawartości miskanta, jednak różnice w średnicy kwiatostanów wahały się w wąskim zakresie 3,9-4,2 cm i nie były widoczne wizualnie. Z kolei u rozchodnika (str. 20) liczba pędów kwiatostanowych wynosiła 5,9-6,7 dla podłoży zawierających do 50% dodatku słomy z miskanta, a dla 70% i 100% miskanta wynosiła 4,7.

5. Wnioski

W przeprowadzonych doświadczeniach podłoża z rozdrobnionej słomy miskanta wykazały swoją przydatność przy produkcji wybranych 6-ciu gatunków bylin i krzewów ozdobnych. Rośliny miały wartość handlową w podłożach z maksymalnie 30% dodatkiem miskanta u hortensji, astra i tawuły, do 50% słomy miskanta w podłożu u rozchodnika i rudbekii oraz we wszystkich testowanych podłożach dla żywotnika. Zmiany właściwości fizycznych podłoży, a szczególnie zmniejszającej się pojemności wodnej wraz ze wzrostem zawartości miskanta, powinny być uwzględnione przy planowaniu kolejnych, aby wyeliminować niedobór wody jako czynnika ograniczającego wzrost i rozwój roślin.

6. Streszczenie

Wzrastające zapotrzebowanie na podłoża ogrodnicze wynika z czynników demograficznych, ekologicznych oraz ekonomicznych. Wrastająca liczba ludności zwiększa zapotrzebowanie na rynkach na rośliny jadalne i ozdobne. Dostępność dotychczas stosowanych składników podłoży zmniejsza się, głównie ze względu na wzrost świadomości ekologicznej związanej z ich pozyskiwaniem. Rośliny energetyczne, charakteryzujące się szybkim przyrostem biomasy i mające stosunkowo niewielkie wymagania agrotechniczne, wpasowują się w ideę zrównoważonego rozwoju. Na szczególna uwagę zasługuje miskant olbrzymi (*Miscanthus × giganteus* Greef et Deu), którego powierzchnia uprawy zwiększa się zarówno w Stanach Zjednoczonych, Kanadzie, jak i w Europie. Doświadcenie dwuczynnikowe prowadzono w latach 2014-2016 na sześciu wybranych gatunkach bylin i krzewów ozdobnych: rudbekii błyskotliwej *Rudbeckia fulgida* 'Goldsturm', astra krzaczastego *Aster dumosus* 'Jenny', rozchodnika okazałego *Sedum spectabile* 'Stardust', żywotnika *Thuja* 'Smaragd', tawuły gęstokwiatowej *Spiraea densiflora* Nutt. ex Torr. et A. Gray oraz hortensji krzewiastej *Hydrangea arborescens* 'Annabelle'. W doświadczeniu testowano 5 mieszanek podłożowych na bazie torfu (T) i słomy z miskanta (M) w proporcjach: 100%T, 70%T:30%M, 50%T:50%M, 70%T:30%M, 100%M. Każde z podłoży dodatkowo poddano trzem praktykom nawożeniowym uwzględniającym dwa typy nawozów (wolno- i szybkodziałający) oraz ich połączenie: Basacote, Basacote+YaraMila, i YaraMila. Podłoża 100%M wykazywały wyższe pH i niższe zasolenie, jak również zawartość azotu i azotanów w porównaniu do podłoża 100%T. Wzrost roślin różnił się

pomiędzy gatunkami, jednak zanotowano tendencję, w której wraz ze wzrostem zawartości miskanta w podłożu, wartości cech biometrycznych malały, a wyjątek stanowił jedynie żywotnik. Rośliny miały wartość handlową w podłożach z maksymalnie 30% dodatkiem miskanta u hortensji, astra i tawuły, do 50% słomy miskanta w podłożu u rozchodnika i rudbekii oraz we wszystkich testowanych podłożach dla żywotnika, co wskazuje na przydatność podłoży z dodatkiem słomy z miskanta w uprawie roślin ozdobnych.

7. Abstract

Increasing demand on horticultural substrates is affected by demographic, ecological and economic factors. increasing population and thus, increasing demand on the market on food and ornamental crops. Increasing human population affects increased demand on food and ornamental crops. Availability of many substrate components is decreasing due to increased environmental consciousness related to their sourcing. Energy crops, characterized by fast biomass production with relatively low agricultural input, fit into definition of sustainable development. Particularly noteworthy among energy crops is giant miscanthus (*Miscanthus × giganteus* Greef et Deu), with its production area increasing lately in the U.S., Canada, as well in Europe. Two factorial experiment was conducted in years 2014-2016 on six selected species of perennials and ornamental shrubs: black-eyed Susan *Rudbeckia fulgida* ‘Goldsturm’, rice buton aster *Aster dumosus* 'Jenny', stonecrop *Sedum spectabile* ‘Stardust’, thuja *Thuja* ‘Smaragd’, white spiraea *Spiraea densiflora* Nutt. ex Torr. et A. Gray and smooth hydrangea *Hydrangea arborescens* ‘Annabelle’. In the experiment 5 substrate mixes based on peat (P) and Miscanthus straw (M) were tested in ratios: 100%P, 70%P:30%M, 50%P:50%M, 70%P:30%M, 100%M. Each substrate was subject to three fertilization practices with two different types of fertilizers (slow-release and easy available) and their combination Basacote, Basacote+YaraMila, and YaraMila. Substrates containing 100%M had higher pH and lower EC, nitrogen and nitrates in comparison to substrates based on 100%P. Growth of tested plants varied between species, however, clear trend was observed: with the increase of miscanthus straw amendment in the substrate, values of tested biometric features of plants were decreasing, and *Thuja* was the only exception from this trend. Plants had reached market values in substrates with up to 30% of miscanthus straw amendment for *Hydrangea, Aster and Spiraea*, up to 50% miscanthus amendment for *Sedum*

and *Rudbeckia* and in all tested substrates for *Thuja*. These results implicate suitability of miscanthus straw based media for cultivation of ornamental plants.

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