Spent Mushroom Substrate as a Transplant Media Replacement for Commercial Peat in Tomato Seedling Production

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Abstract

Replacement of commercial peat media buy local composts would greatly improve transplant seedling production efficiency. The quality and effectiveness of substrate mushroom compost (SMS) was evaluated as a complete substitute for promix (PM) in the germination, growth and development of tomato seedling. Contrasting physicochemical properties were observed for the SMS and PM, both substrates falling outside the ideal media range for many properties. Germination percentage was > 95 % for both SMS fine (SMS_F) and PM treatments. The two SMS course (SMS_C) treatments showed significantly lower germination. For all growth parameters the fertilized SMS_F treatment showed the greatest values at all sampling times. The non-significant difference between the fertilized PM and unfertilized SMS_F treatments was notable. SMS treated seedlings were taller (32 %) and possessed a greater number of leaves (12 %) at 5 weeks after seeding (WAS) than PM seedlings at 6 WAS. SMS was shown to be a better media for tomato seedling production.

Keywords: SMS compost, Transplant production, Promix, Tomato

1. Introduction

Nursery production of seedlings of agriculturally important crops has been practiced for many years and continues to play a major role in the provision of vigorous, disease-free plants towards sustainable crop production. This system allows producers to successfully manipulate the growing environment around germinating seeds to provide conditions that are optimal for growth and development. Uniform seedling emergence and rapid growth are essential for efficient production (Herrera et al., 2006). To this end the nature, components and properties of the growing media are critical.

As with many countries, the nursery industry in Trinidad and Tobago based their growing media on peat, with the use of numerous commercial products. The reliance on peat-based products is two-fold; firstly, this material has been shown to display desirable properties including high water holding capacity, good consistency, low strength and excellent porosity (Wilson et al., 2002). However, peat is a natural, non-renewable resource and its utilization is producing an environmental concern (Abad et al., 2001). The diminishing reserves have led to price increases, which results in long term unsustainability. Concerns of food insecurity and sufficiency become real with the dependence on imported nursery media as a vital input of the food-production system. Sterrett (2002) commented that the continued use of commercial peat would require consideration for replacement in the medium to long term. The second aspect of the reliance on peat products surrounds the lack of competitive substitute substrates.

Several organic waste products have been studied as alternatives for peat in commercial nursery production or container cultivation. Spent mushroom substrate (Romaine and Holcomb, 2000), sewage sludge compost

(Perez-Murcia et al., 2006), municipal solid waste compost (Ostos et al., 2008), animal manure compost (Jayasinghe et al., 2010), green waste compost (Benito et al., 2005) and agro-industrial waste compost (Bustamante et al., 2008), have all shown very good results as growing media instead of peat or when used as a diluent. One common prerequisite across the diversity of composts in their influence on productivity was compost maturity. Immature compost has been associated with adverse effects, particularly due to the increase salinity on seeds and seedlings (Garcia-Gomez et al., 2002; Bustamante et al., 2008).

Spent mushroom substrate, the by-product of the commercial production of the button mushroom *Agaricus bisporus*, has been identified as an alternative to peat, as a growing media substrate component. However, only a few comparative studies have been performed examining its potential. Medina et al. (2009) supported by others have shown general trends with increasing amounts of SMS in the growing media. Water holding capacity (AWHC) decreased with increasing proportion of SMS in the media, whilst pH, EC and macronutrient levels increased. The greatest plant growth response and largest yield have usually occurred when composts constituted only a relatively small proportion (25-50 %) of the volume of the greenhouse container media (Perez-Murcia et al., 2006; Grigatti, et al., 2007; Bustamante et al., 2008). The major constraint identified when using compost only media, is phytotoxicity associated with high salinity (Sanchez-Monedero et al., 2004). For SMS, Medina et al. (2009) attributed this to the inclusion of other materials together with the carbon source, such as animal manures and $CaSO_4$. Romaine and Holcomb (2000) in their study examined particle size in addition to salinity and inferred that the unfavourable plant growth response observed by other investigators with media containing high levels of SMS was related to its structural features rather than salts per se.

The fact that growth improved by addition of SMS to seedling media suggested that plants responded to the nutrients that were likely being released from the SMS, and possibly to desirable microbial activity (Romaine and Holcomb, 2000). The replacement or substitution of peat based products with SMS has the potential to reduce nutritional requirements of seedlings and containerized plants. The objectives of the present work were to evaluate the influence of particle size, fertilization and combinations of SMS and P, on plant germination and plant growth response of tomato seedlings. Special emphasis was directed towards the feasibility of total replacement of P by SMS.

2. Materials and Methods

2.1 General Preparation of SMS

Fresh SMS was obtained from a commercial mushroom operation, located locally, with the major component being sugarcane bagasse. The SMS was air dried and along with the commercial peat (Premier Promix BX, Premier Horticulture Inc., Quakertown, PA), screened to pass a 6.25 mm mesh. Additionally, the SMS was sieved through a 2 mm mesh screen to generate two size classes as follows; coarse (> 2mm, < 6.25 mm) and fine (< 2 mm). Coarse SMS (SMS_C) was also mixed at a 50:50 v/v ratio with PM to generate four substrates. The substrates consisted of PM, SMS_C, SMS_F and SMS_C+PM. The treatments were combined in a factorial design with two fertilizer levels; a no fertilizer control and a NPK solution at 100 ppm N. The SMS fine (SMS_F) was not blended with PM as this treatment was intended for complete replacement.

The six treatments were prepared in bulk and transferred to plastic plug trays with 72 cuboid cells. One tomato (*Lycopersicon esculentum* var. heat master) seed was sown per cell. The treatments were laid out in a completely randomized pattern with two replicates per treatment. An entire seedling tray was used as a replicate. Germination was performed under ambient conditions (typical of local production) in an unheated perspex covered greenhouse, protected under shade cloth allowing 60 % sunlight. Trays were exposed to natural sunlight after 72 hrs. Nursery trays were irrigated daily by means of a sprinkler system and fertigated once weekly with water containing a soluble fertilizer (Nutrex 20-20-20) at 100 ppm N. Germination percentage was determined by counting the number of germinated seeds after 72 hrs. Germination was monitored up to three weeks after seeding. Plant growth parameters (number of leaves and plant height) were measured after the third week, at weekly intervals throughout the study. Upon attaining commercial transplanting size (six weeks), 24 whole plants, including roots, were harvested from the middle of the tray, excess media washed off and weighed to determine fresh weight. Plants were further dried in a force draft oven at 65 °C for 72 hrs to determine dry weight.

2.2 Analytical Methods

Electrical conductivity and pH of the substrates were measured in a water extract (substrate: distilled water ratio of 1:5) (TMECC, 2001). For water soluble nutrients, phosphorus (P) and total available nitrogen (TAN) were determined colorimetrically. Potassium was measured by atomic absorption spectrophotometry. Total N was determined by the Kjeldahl method according to Bremner (1996) and total organic carbon (TOC) by loss on ignition at 430 °C for 24 hrs (Navarro, et al., 1993). The C/N ratio was determined mathematically from the percentages of its components. Physical properties of each treatment were determined using procedures described by TMECC (2001). Porosity (TPS) was determined by saturation under zero tension. The mass of water at saturation was divided by the bulk density. Aeration porosity (AS) was similarly measured after saturation. Samples were left to drain at 4 kPa on a tension table for 48 hrs. Bulk density (BD) was determined by dividing the oven dried weight of each substrate by its bulk volume. Water holding capacity (TWHC) was measured gravimetrically, after saturating and allowing substrates to drain naturally under the influence of gravity. Samples of the air dried substrates were passed through a series of sieves, from 5.6 – 0.10 mm, to determine their particle size distribution. Coarseness index (CI), expressed as the weight percentage of particles with diameters > 1mm (Richards et al., 1986) was determined. All measurements were performed four times.

2.3 Statistical Analysis

Substrate characterization data were compared using *t-tests*, whilst substrate evaluation data was subjected to GLM analysis of variance to determine treatment effects. Treatment means were compared using Fisher's protected LSD test at $p < 0.05$. Treatments were analyzed independent of time but trends over time were analyzed for plant height and No. of leaves. Mintab 15 statistical software was used to perform all analyses.

3. Results and Discussion

3.1 Physical properties of the nursery media

Jayasinghe et al. (2010) identified the physical properties listed in Table 1 as key determinants in preparing containerized media. BD varied significantly among the media. PM and SMS_C treatments showed the lowest and highest BD respectively. Importantly, all media were within the acceptable range for an ideal substrate (Abad et al., 2001). Low BD suggests high porosity. Of the four treatments only SMS_F showed a significantly greater TPS (85.3 %). Additionally, it was the only treatment falling within the acceptable range. The exclusion of material > 2 mm, lead to a more homogenous media with increased porosity associated with reduced particle size (Brady and Weil, 2008). Greater AS was seen in media containing SMS_C reflective of the greater proportion of particles with size > 1 mm (Bustamante et al., 2008). CI as defined by Richards et al. (1986), represents the cumulative volume percentage of particles > 1 mm and should be directly related to AS. The pore sizes associated with such particle would be occupied by air under unsaturated conditions. Dissimilar differences were seen among all treatments which cannot be explained by the relationship between AS and CI. Whilst SMS_C had the greatest AS and PM the lowest, PM showed the greatest CI, significantly ($p < 0.05$) different from SMS only media. The unusual relationship observed provide reason for evaluating a wide range of parameters in assessing media performance for transplant culture. AS increased with addition of SMS_C to PM. This result has been reported by other authors (Medina et al., 2009, Garcia-Gomez et al., 2002). Only SMS_C showed AS values in the ideal range. All other media had lower than optimal values. This fact could severely limit O_2 concentration and exchange within the media, thereby inhibiting plant growth.

The low AS and the high CI of PM is combined with a lower than ideal TWHC. Medina et al. (2009) reported a decrease in TWHC with increasing proportion of SMS in the media. The combination of PM and SMS_C resulted in an increase in TWHC above both individual media, the difference being significant for SMS_C. The differences between our study and Medina et al. (2009) could have resulted from differences in particle size distribution of the substrates. SMS_F had the lowest CI (only substrate in the acceptable range) and the highest TWHC, attributed to the predominance of fine material. The media used were all outside the ideal range for TWHC, however, value were comparable to other authors (Medina et al., 2009).

3.2 Chemical Properties

The pH and EC of compost media was significantly higher than that of the commercial peat media. Equal volumes of SMS_C and PM had a dilution effect, significantly increasing and decreasing the pH and EC respectively, compared to P and SMS only. All treatments except P was within the acceptable pH range (Abad et al., 2001). However, only the PM media showed EC values comparative to an ideal substrate. The SMS media was highly saline (Maher et al., 2000, Jordan et al., 2008). This feature is mostly responsible for limiting the use of SMS as a potting substrate, soil amendment and fertilizer source. Similar to Jordan et al. (2008) the high salinity is related to high levels of available K. Medina et al. (2009) also related high EC of SMS based media to increase ion concentrations, which they inferred was the result of addition of manures, $CaSO_4$ etc. during compost preparation for mushrooms.

Generally, SMS media showed significantly greater macronutrient concentration than peat based media. TAN was significantly lower in P, less than the ideal range, which would limit its ability to support plant growth without external fertilization. For PM, TN was also low and the C/N ratio was 123, indicating that mineralization and N availability would be limiting. Comparatively, SMS media showed available nutrient levels in excess of that for an ideal substrate, alluding to their potential as a nutrient source. SMS has been shown to increase the nutrient supplying power of growing media (Medina et al., 2009, Benito et al., 2005). Total organic carbon was greatest for PM and lowest for SMS_F. This influenced the C/N ratio. SMS only treatments showed C/N ratios within the acceptable range, whilst peat based media was higher. Although this may not significantly limit use of the later for seedling production, it may lead to increased cost of production, associated with fertilizer inputs.

3.3 Seed germination, seedling growth and transplant production

SMS_C resulted in significantly lower germination compared to other treatments, although germination continued after 72 hrs (Table 3). Romaine and Holcomb (2000) observed a similar outcome when unsieved SMS was used alone or in combination with perlite. They alluded to the low TWHC of the unsieved SMS and consequently, undesirable high aeration porosity. However, the TWHC of the SMS_C used in our study although significantly different from the SMS_F media, was non-significantly different to PM. Aeration porosity was also within the acceptable range for SMS_C. Since the ability to retain water was not limiting, other media properties may have been culpable.

In the studies conducted by Romaine and Holcomb (2000) they pre-treated the SMS based media by leaching for 2 days, practically eliminating the major limiting factor associated with its use, elevated EC. Herrera et al. (2008), Bustamante et al. (2008) and Medina et al. (2009) all reported reduced seed germination with increased compost composition in the media, with the reason being high salinity. Pinamonti et al. (1997) further elaborated this effect identifying that high EC values reduce water retention, negatively affecting the imbibing process. Salinity was ruled out in this study since the SMS_F media showed non-significant differences with the commercial peat control media, both showing > 95 % germination. Observations of the SMS_C treatment revealed a sealed layer at the surface. Apparently a crust formed from moisture loss at the media surface, probably due to particle segregation, with the lower levels retaining adequate moisture. The crust was impenetrable to the germinating seedling. Greater homogeneity of the SMS_F treatment prevented crust formation by minimizing moisture loss. Medina et al. (2009) who used a similar sized material and reported similarly low germination could have also been exposed to this phenomenon, although it may be unlikely since germination was conducted at 90 – 95 % relative humidity. Inclusion of PM reduced the inhibitory effect of the SMS_C, significantly increasing the germination over the SMS_C only treatment. It is worth mentioning that EC was significantly lower in this media compared to the SMS_C only treatment.

Plant growth and yield parameters for Tomato seedlings varied significantly among the nursery media and fertilizer treatments (Table 3). At five WAS the fertilized SMS_F media showed the greatest plant height, with the unfertilized SMS_F having the second tallest plants. The latter result bears much practical significance as the value was significantly ($p < 0.05$) greater than the fertilized treatments containing PM. The SMS_F treatment naturally supplied all the essential nutrients required for proper growth and development, a claim that cannot be substantiated for the peat media. Available levels of the macronutrients (Table 2) were much greater in the SMS than that applied as a standard fertilizer supplement for nursery cultivation. Moreover, Medina et al. (2009) showed that SMS contains significantly higher available quantities of secondary and micronutrients, the majority of the latter being required during early growth and development (Dursun et al., 1999). The extremely low plant heights for SMS_C could be related to the poor and prolonged germination.

The main effects of media and fertilizer on plant height over the sampling period are shown in Figure 1. Tomato seedlings growing in SMS_F not only showed the greatest plant heights for all weeks, but also showed the fastest growth rate. Seedling height was greater for SMS_F at 5 WAS than PM at 6 WAS, implying greater seedling vigour and possibility for reducing the nursery grow-out period. This equates to greater turnover and efficiency in transplant production. Fertilizer influence was expressed 5 WAS where media receiving fertilizer showed greater plant heights. The high fertility of the SMS masked the effect of additional fertilizer and only when the external source significantly influenced the SMS_F treatment, did the main effect become observable. Tomatoes have been reported to have a high nutrient requirement (Hedge, 1997).

As was the case for plant height, no. of leaves showed an identical trend over time for media composition and fertilizer treatment (Figure 2). For all weeks, seedlings growing in SMS_F showed a significantly greater no. of leaves. This media as well as the SMS_C+PM showed greater rates of leaf generation than other media. The no. of leaves present for SMS_F seedlings at 5 WAS was similar or greater than the other media at 6 WAS. At 1 and 4 WAS media composition interacted significantly with fertilizer affecting the no. of leaves (Table 3). Non-significant differences were seen between SMS_F fertilized and both P-only treatments, but the latter were significantly greater than the mixed treatments. At 4 WAS SMS_F plants had the most leaves followed by the fertilized mixed media. The fertilized PM treatment showed non-significant differences with the unfertilized SMS_F media.

Following a similar pattern, seedling yield indicators (fresh and dry weight) was significantly higher for fertilised SMS_F media. Seedlings grown in SMS_F displayed better quality and suitability for transplanting. Herrera et al. (2008) inferred similarly about municipal solid waste compost used to grow tomato seedlings. The increase in plant biomass with the use of compost in container media have also been reported by Bustamante et al. (2008), Garcia-Gomez et al. (2002), Perez-Murcia et al. (2006). All these authors attributed the increase to the input of nutrients provided by compost, especially the macronutrients. However, the reported study showed that external fertilization resulted in significantly greater DM in the SMS_F treatment, implying that plant nutrient requirements also dictate the influence of the compost. Medina et al. (2009) in their studies on SMS compost as a substrate component reported that tomato seedlings died in compost treatments with low nutrient concentrations. The indifference between the unfertilized SMS_F and the fertilized PM implies that the SMS can be used as a substitute for PM without jeopardizing transplant growth, development and vigour, without the need for external fertilization.

4. Conclusion

SMS was an effective substitute to traditional PM for tomato seedling production, when sieved < 2 mm. Without mechanical size reduction, crusting, particle segregation as well as moisture retention limited seedling emergence and development. High EC levels present in the SMS did not influence tomato seed germination or DM production. Seedling growth characteristics as well as yield were greatest for SMS_F media. Importantly, the unfertilized SMS_F treatment showed similar responses to the fertilized commercial peat media. Mixing the SMS_C with PM seemingly neutralized the limiting nature of the SMS, but did not improve the response of tomato seedlings.

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Abbreviations

PM – Pro mix

SMS – Spent mushroom substrate

WAS – weeks after seeding

AWHC – available water holding capacity

EC – electrical conductivity

N - Nitrogen

P - Phosphorus

K - Potassium

C/N – Carbon/ Nitrogen

TPS – Total pore space

AS – Aeration porosity

TOC – Total organic carbon

TAN – Total available nitrogen

BD – bulk density

CI – Coarseness index

TWHC – total water holding capacity

TMECC – Test methods for the examination of composts and composting

LSD – Least significant difference

GLM – General linear model

Table 1. Physical properties of study media: ideal media (IM), promix (PM), spent mushroom substrate coarse (SMS_C), spent mushroom substrate fine (SMS_F) and mixture of PM and SMSC at 50% v/v ($PM+SMS_C$)

Media	BD	TPS	AS	CI	TWHC
	g cm^{-3}	←	(%)		→
IM[a]	< 0.40	> 85	20-30	30-45	60-80
PM	0.15 d	68.6 b	7.79 c	71.9 a	42.5 bc
SMS_C	0.27 a	67.9 b	22.8 a	66.3 b	40.6 c
SMS_F	0.25 b	85.3 a	8.18 c	37.7 c	48.5 a
$PM+SMS_C$	0.17 c	66.8 b	16.8 b	72 a	45 b

BD: bulk density; TPS: total pore space; AS: air space; CI: coarseness index; TWHC: total water holding capacity; IM: ideal media

[a] According to Abad et al. (2001).

Mean values in columns followed by the same letter are not statistically different (P < 0.05) according to LSD

Table 2. Chemical properties of study media: ideal media (IM), promix (PM), spent mushroom substrate coarse (SMS_C), spent mushroom substrate fine (SMS_F) and mixture of PM and SMSC at 50% v/v ($PM+SMS_C$)

Media	pH	EC	TOC	TN	C/N	TAN	P	K
		(dS/m)	← (%)	→		← (mg/kg)	→	(g/kg)
IM[a]	5.3-6.5	< 0.5	NA	NA	20-40	100-199[b]	6-10	0.15-0.25
PM	5.15 c	0.43 d	80.3 a	0.65 d	123 a	17.3 d	106 d	0.26 d
SMS_C	6.28 a	8.51 b	54.5 c	1.67 b	32.7 c	554 b	515 b	4.4 b
SMS_F	6.32 a	9.53 a	49.5 d	1.80 a	27.3 d	608 a	660 a	4.73 a
$PM+SMS_C$	5.79 b	2.79 c	65.7 b	1.13 c	59 b	304 c	447 c	3.07 c

EC: electrical conductivity; TOC: total organic carbon; TN: total nitrogen; TAN: total available nitrogen; IM: ideal media

[a] According to Abad et al. (2001).

[b] Refers to NO_3^- -N only

Mean values in columns followed by the same letter are not statistically different (P < 0.05) according to LSD

NA means not available

Table 3. Comparative effects of the different nursery media on tomato germination, plant height, No. of leaves, and total fresh and dry weight (expressed as g/ seedling)

Treatment[a]	Germination	Plant Ht.	No. of Leaves		Fresh Wt.	Dry Wt.
	%	cm	W1	W4	g	g
SMS_C-F	17.6 c	5.058 e	1.500 cd	7.917 f	0.920 de	0.055 de
SMS_C-C		4.175 e	1.167 d	7.750 f	0.459 e	0.027 e
$PM+SMS_C$-F	47.7 b	11.20 cd	1.250 d	20.75 b	3.127 c	0.187 c
$PM+SMS_C$-C		10.06 d	2.250 c	15.83 d	2.724 c	0.163 c
SMS_F-F	95.33 a	26.17 a	5.083 a	24.67 a	4.768 a	0.286 a
SMS_F-C		19.67 b	4.083 b	18.25 c	3.488 bc	0.209 bc
PM-F	96.27 a	12.98 c	4.333 ab	17.75 c	3.990 ab	0.239 ab
PM-C		11.71 cd	4.583 ab	13.67 e	1.688 d	0.101 d

SMS_C: spent mushroom substrate coarse (F: fertilized; C: control); $PM+SMS_C$: promix plus spent mushroom substrate coarse; SMS_F: spent mushroom substrate fine; PM: promix

[a] Fertilizer addition commenced two weeks after seeding.

Mean values in columns followed by the same letter are not statistically different (P < 0.05) according to LSD

A

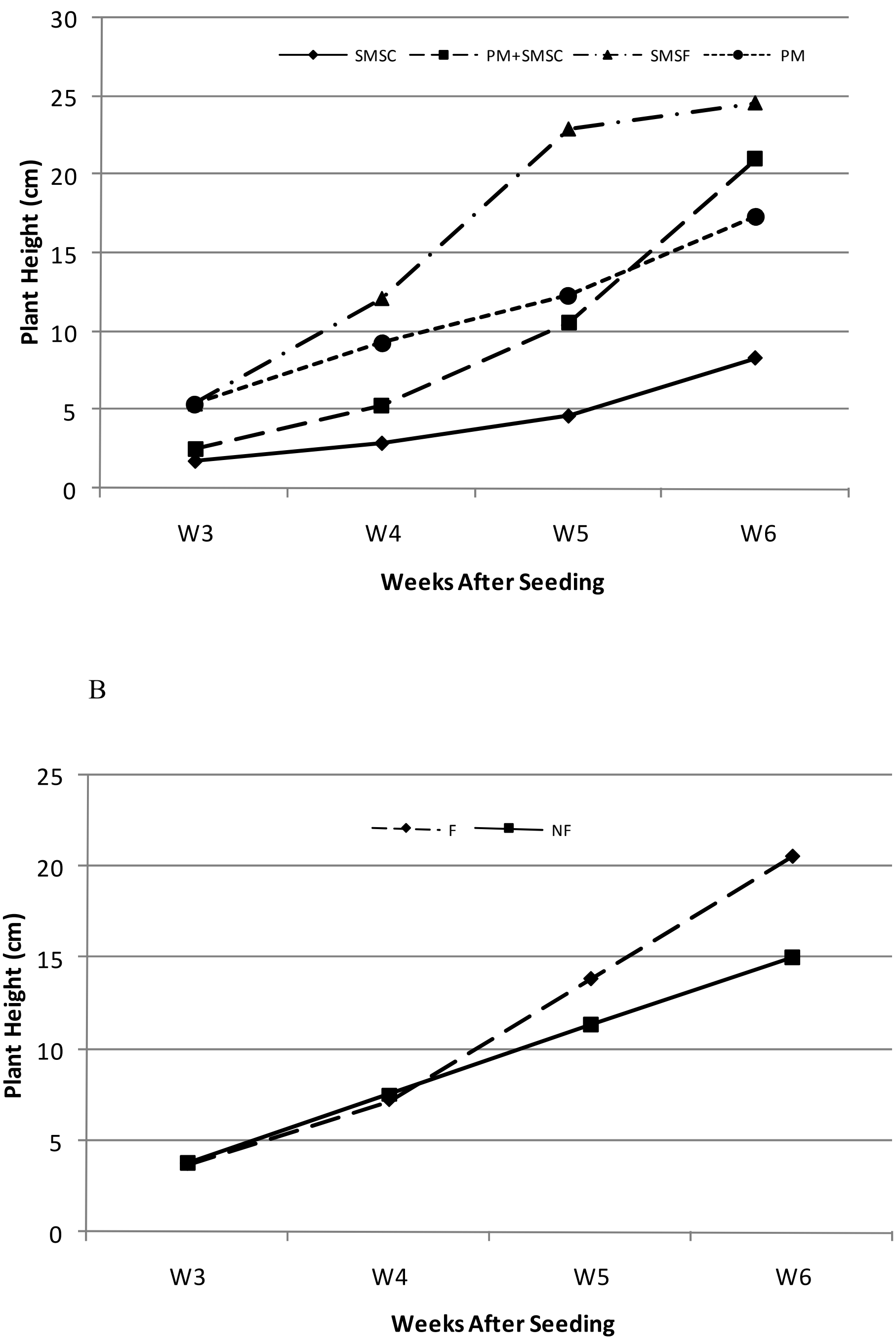

Figure 1. Tomato seedling plant height measured at weekly intervals for four (4) nursery media (A) and two (2) fertilizer treatments (B)

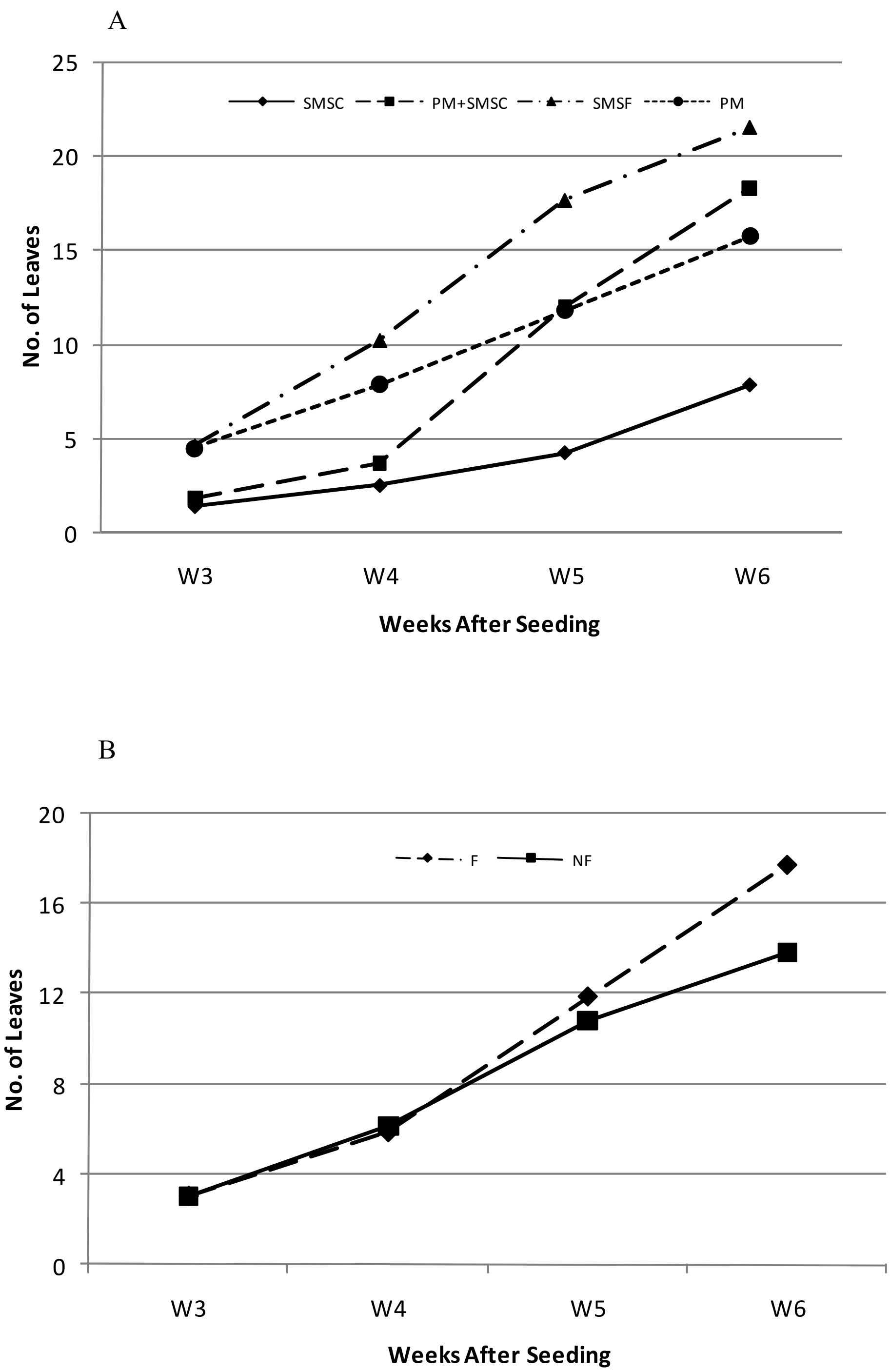

Figure 2. No. of tomato seedling leaves measured at weekly intervals for four (4) nursery media (A) and two (2) fertilizer treatments (B)