Evaluation of Selected Controlled-Release Fertilizers

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To compare the performance of the selected controlled-release fertilizers (CRF) as determined by final growth of containerized spiraea as measured by top dry weight in particular, and by some other plant growth parameters (plant height and width), EC and pH measured at various intervals. Additional objectives were to quantify amounts of NO_3-N leaching from container-grown spiraea under various CRF rates and to see the over wintering performances and salt toxicity if nay from the selected CRF products.

MATERIALS/METHODS

On 30th May 2008, 15-cm tall rooted cuttings of *Spiraea japonica* 'Anthony Waterer', were potted in #2 (6 L, 21 cm dia × 21 cm deep) nursery containers filled with a growing medium consisting of (by volume) 65% pine bark: 25% peat moss: 10% compost [Gro-Bark (Ontario) Ltd., Milton, ON]. Controlled-release fertilizers with micro nutrients were incorporated with the growth medium at rates (kg product per m^3 or kg N per m^3) shown in Table 1 on 29 May (day before potting). Among the seven selected CRFs, some were newly formulated and a few were checks to compare the results. However, to avoid bias their identities were not disclosed and were denoted as CRF products A, B, C, D, E, F and G.

Plants were hand-sprinkled lightly each day with tap water to avoid any leaching from the containers until they were transferred to experimental plots on 5th June. On this date, containers were spaced 45 × 45 cm on a crushed stone base and subjected to 15 min of drip irrigation (equivalent to about 500 ml) through one ½ gal turbulent flow emitter per container (NIBCO Irrigation Systems, IN), once/day in the morning throughout the whole growing period that yielded a moderate-leaching fraction of d" 30%. The experiment was a two-factor factorial (7 CRFs × 3 CRF rates) with all treatments arranged in a randomized complete block design. There were four replications and four plants per plot.

Sampling and analysis

Before using, duplicate samples of the medium were collected and analyzed for pH, EC (a measure of total soluble salts concentration), and selected nutrients (Agri-Food Laboratories, Guelph, ON) and physical properties (OMAFRA, 2003). At the start, the pH and EC were 6.1 ± 0 and 0.72 ± 0 dS•m-1, respectively, the concentrations of nutrients (mg•L-1) as measured in saturated paste extracts were as follows: NH_4-N, <0.05; NO_3-N, 3.3 ± 0; P, 5.14 ± 0.56; K, 142 ± 21; Ca, 25 ± 4; Mg, 12 ± 0.35; Na, 17 ± 2.7; Cl, 122 ± 28; SO4, 2.5 ± 0.4; Fe, 1.07 ± 0.13; Mn, 0.42 ± 0.3; Zn, 0.09 ± 0; Cu, 0.04 ± 0.002; B, 0.31 ± 0; Mo, <0.01; and Al, 1.76 ± 0.08. The physical properties of the substrate were: total porosity, 72 ± 1.3%; aeration porosity, 23 ± 0.1%;

Table 1. Fertilizer formulations, duration, N contents and rates of the seven selected controlled-release fertilizers applied to spiraea during 2008.

Fertilizer	Description (Duration)	Nitrogen content	Fertilizer product (CRF) kg/m^3		
			Low (0.6 kg N/m^3)	Medium (0.9 kg N/m^3)	High (1.2 kg N/m^3)
Product A	3-4 months	16%	3.75	5.63	7.50
Product B	5-6 months	16%	3.75	5.63	7.50
Product C	5-6 months	17%	3.53	5.29	7.06
Product D	5-6 months	15%	4.00	6.00	8.00
Product E	8-9 months	15%	4.00	6.00	8.00
Product F	8-9 months	18%	3.33	5.00	6.67
Product G	8-9 months	15%	4.00	6.00	8.00

water retention porosity, 48 ± 1.6%; and bulk density, 0.34 ± 0.01 $g.cm^{-3}$.

Starting on 9 June, irrigation leachate was collected once weekly (every Monday) from one randomly selected container per treatment and replicate for 13 weeks. The leachate volume and its pH and EC were measured, and the NO_3-N concentration as well using auto analyzer (Astoria-Pacific Inc., Oregon, USA).

On 15 September (harvest), plant height and width were measured (all four plants of each plot) and samples of fully-mature leaves were collected from two of the four plants of each plot, dried at 50°C for one week, weighed, ground, and analyzed for N, P, K, Ca, Mg, S, Zn, Mn, Cu, Fe, and B (Agri-Food Laboratories, Guelph, ON). The shoots of the same two plants of each plot (stems and remaining leaves) were removed at substrate level, dried (also for one week at 50°C), and weighed. Dry weight of the leaf samples were added to the final dry weight of the shoot. The other two plants from each plot were over wintered for further study. Throughout the growing season visual observations and overall plant growth and health were noted.

Statistical analysis

Data for top dry weight, plant height, width and foliar nutrient responses were subjected to analysis of variance using SAS and regression analysis conducted over CRF rates. When any two regression responses were similar ($P < 0.05$), they were combined. Means were separated by the Least Significant Difference (LSD) test. These data were also subjected to correlation analysis as well as the EC and NO3-N concentrations in the leachates.

RESULTS

Visual observations:

Plants started showing treatment effects after about four week of potting. During that time, spiraea plants in treatments 16, 17 and 18 (product F at 0.6, 0.9 and 1.2 kg N/m^3 rates respectively) were observed with yellowish leaves, and reduced growth than other treatments indicative of starvation. However, after about six weeks of potting, the plants seemed started recovering from starvation. In general, plants treated with higher CRF rates had comparatively bigger canopy and plants with bigger canopy flowered profusely throughout the growing season compared to plants with smaller canopies. Phenotypic scoring at that time (six weeks after potting) depending on visual observation on a 1 to 10 scale (1 = worst, 10 = best) showed that (Table 2a) showed that fertilizer F performed very poorly at all rates and fertilizer G performed best except at lowest rates. Other fertilizers were close in their performance.

Phenotypic scoring was also done at the end of growing season similarly (Table 2b). It was observed that at low and moderate rates, fertilizers B and F performed poorly and at high rates fertilizer C, F and G performed better compared to others. At the end of growing season, it was also observed that at rate 0.6 kg N/m^3, plants

Table 2(a). Phenotypic scores of spiraea plants for different controlled-release fertilizer brands and rates at six weeks after potting.

CRF rate	Controlled-release fertilizers						
(kg N/m^3)	A	B	C	D	E	F	G
0.6	8	7	7	6	7	4	4
0.9	9	8	8	8	8	5	10
1.2	9	9	8	9	8	7	10

Table 2(b). Phenotypic scores of spiraea plants for different controlled-release fertilizer products and rates at the end of growing season.

CRF rate	Controlled-release fertilizers						
(kg N/m^3)	A	B	C	D	E	F	G
0.6	6	5	7	6	7	5	7
0.9	8	6	8	7	8	7	9
1.2	8	8	9	8	8	9	9

seemed to have run out of nutrients for all fertilizer products except for fertilizer G.

Top dry weight

End of season top dry weight (TDW) of spiraea differed significantly between different CRF products and rates. However, their interactions were not significant. In fact, interactions between CRF products and CRF rates were not significant for none of the plant parameters studied and also for none of the nutrient elements.

Controlled-release fertilizers A, B and G had the highest (46 - 47 g/plant) and CRF F had the lowest (35 g/plant) end of season top dry weights of spiraea (Fig. 1). CRFs C (44 g/plant) and E (45 g/plant) had comparable TDWs, however were grater than that of CRF D (41 g/plant). Spiraea TDW linearly increased with increased rates of CRF without any signs of isotherm (Fig. 2). Contrast analyses between different CRF products were not significant except for A Vs G, C vs G and D vs G.

Plant height and width

CRF D had the highest (30.80 cm) and CRF F had the lowest (28.20 cm) plant height. However, CRFs B and G were comparable to CRF D and CRFs A and C though were comparable to both E and G, had greater plant heights than CRF F (Fig. 3).

In general, differences in plant widths between different fertilizer products were minimal (about 2 cm or less) however, were statistically significant. Fertilizer products A, B, C, E and G had greater and comparable plant heights compared to D and F (Fig. 4).

NO_3-N concentrations in leachate

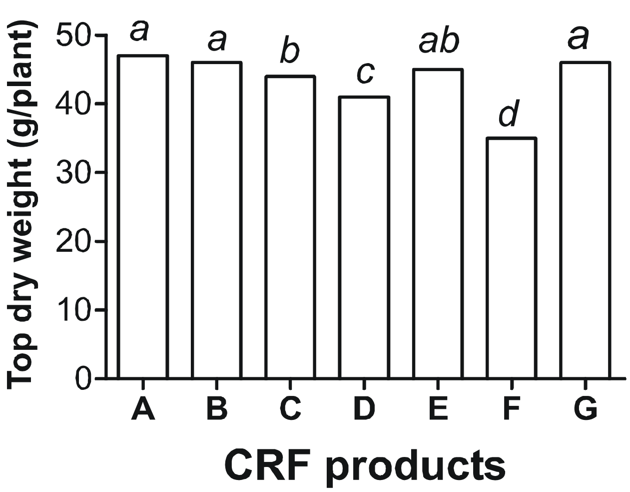

Figure. 1. Top dry weight response of container-grown spiraea to different CRF products.

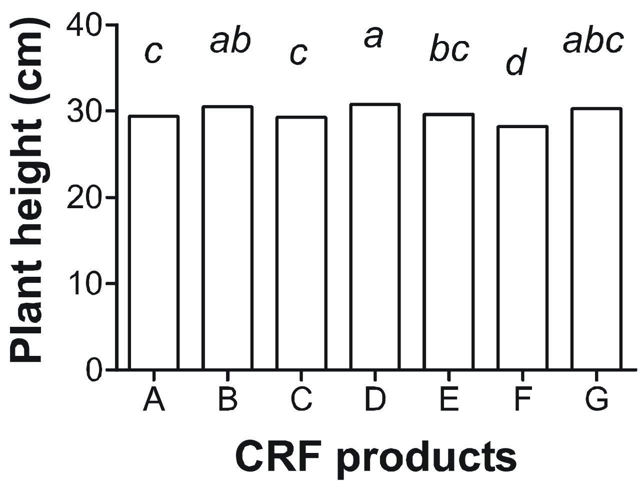

Figure. 3. Height of container-grown spiraea in response to different CRF products.

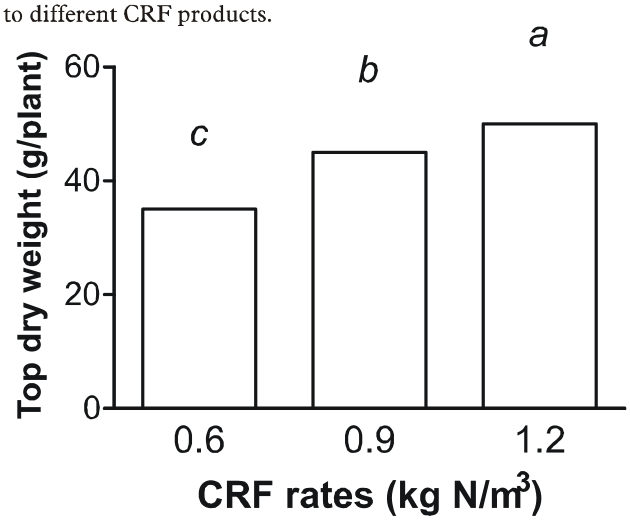

Figure 2. Top dry weight response of container-grown spiraea to different CRF rates.

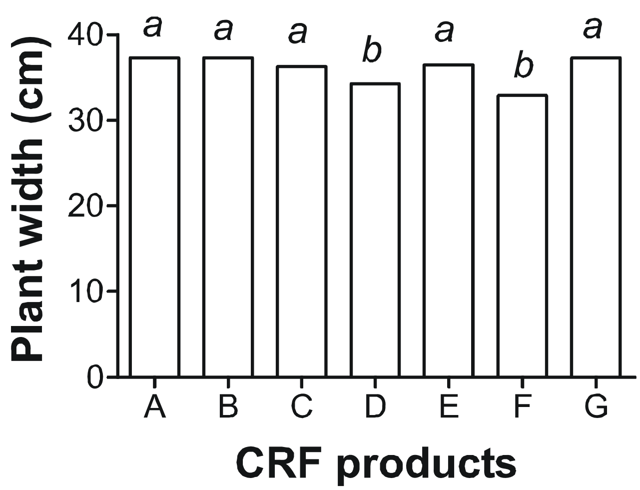

Figure 4. Width of container-grown spiraea in response to different CRF products.

Concentrations of NO_3-N in leachates increased with increasing CRF rates. Also pattern of NO_3-N leaching over time were similar between different CRF rates. However, very distinctive differences were noticed between different CRF products (Fig. 5). CRF products D and G had had high initial NO_3-N concentrations in the leachate. Thereafter it gradually reduced throughout the remainder of the experiment. While CRFs A and B had similar initial NO_3-N concentrations in the leachate as CRFs D and G, kept increasing up to about five weeks, thereafter gradually reduced throughout the remainder of the experiment. In contrast, CRFs C and E had a typical symmetrical curve pattern, low initial NO_3-N concentrations in the leachate, thereafter sharply increased up to six weeks and decreased sharply throughout the remainder of the experiment. Whereas, CRF F had very low NO_3-N concentrations in the leachate till three weeks, then gradually increased to its peak after about seven weeks, thereafter gradually decreased throughout the remainder of the experiment. In general, the concentrations of leachate NO_3-N peaked within 4-6 weeks. Values were highest (up to about 70 mg•L^{-1}/day) at 1.2 kg N/m^3 followed by 0.9 kg N/m^3 (maximum about 50 mg•L^{-1}/day) and 0.6 kg N/m^3 (less than 20 mg•L^{-1}/day).

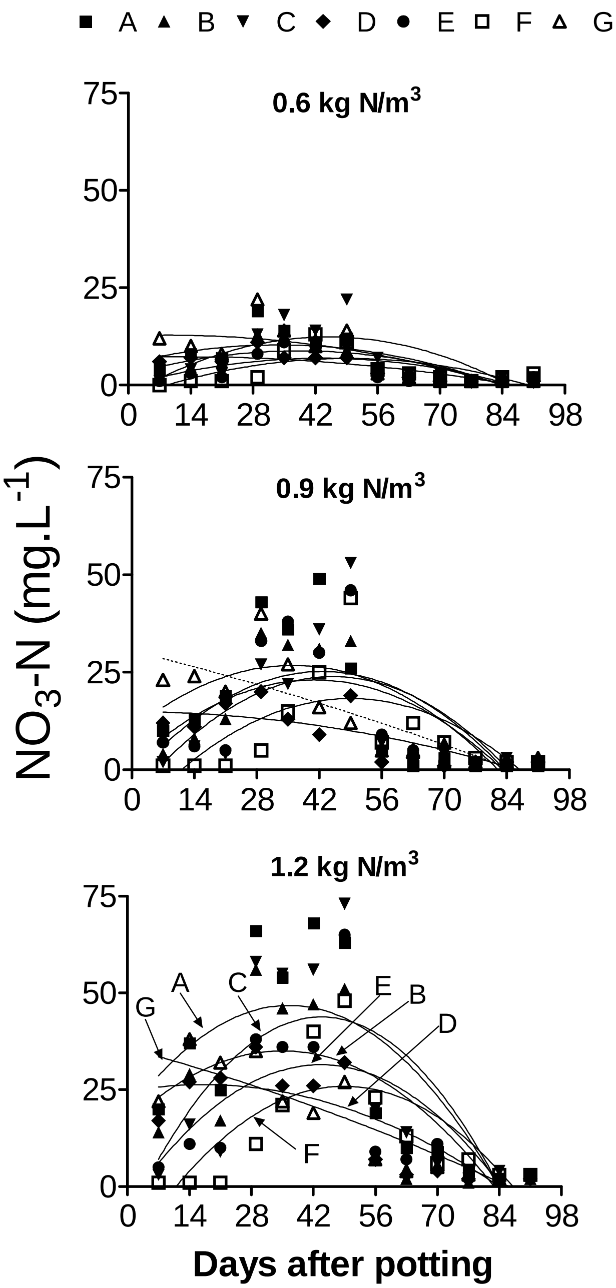

Fig. 5. Concentrations of leachate NO_3-N from container-grown spiraea under various (0.6, 0.9 and 1.2 kg N/m^3) CRF rates.

EC and pH (container leachate).

Leachate EC levels increased with increased rates of CRF except for few weeks before harvest (Fig. 6). Throughout the growing season, the leachate EC levels of all fertilizer treatments were within about 1.0 to 1.7 dS.m^{-1}. The EC values were greater at the beginning of the experiments at three CRF rates and reduced gradually up to about eight weeks. Thereafter EC values showed some increasing trend during the reminder period of the study.

EC levels were also measured for one pot of each treatment on April 7, 2009 to test for high EC levels from overwintering. Because only one repetition was measured statistical analyses could not be performed the raw data values for each pot measured are included in Table 3.

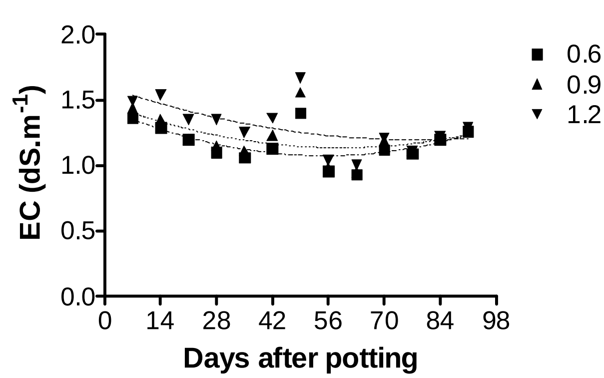

Fig. 6. Electrical conductivity of the container leachate at different CRF rates and at diffenent days after potting.

The range in pH values over all dates were higher (6.4-8.3) than those recommended for nursery crops (pH 5.2 to 6.2; Mathers 2000) and did not vary between different CRF rates, although this did not appear to detrimentally affect plant growth and quality. Leachate pH levels were very similar between CRF products and rates increased gradually and similarly throughout the entire growth period (Fig. 7).

Tissue analysis

All the nutrients were in sufficient levels except Zn and Cu (Table 4). Zinc contents were at high levels (140-205 mg•L^{-1}) and Cu contents were not even at low level (about 3 mg•L^{-1}).

CRF products C, E and F had the highest (2.32-2.43%) and comparable tissue N contents and CRF A had the lowest (2.07%) tissue N contents. However, CRF products B and D were comparable to CRFs A and G however, CRF G had significantly greater tissue N contents than CRF product A.

CRF product D had the highest (0.29%) and CRF F had the lowest (0.21%) tissue P contents. However, CRF products C and G were comparable

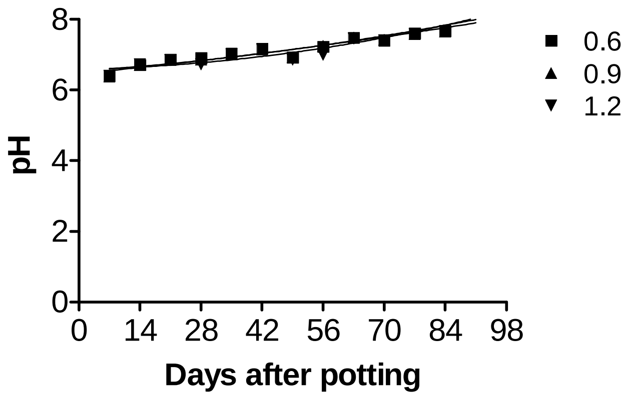

Fig. 7. pH of the container leachate at different CRF rates and at different days after potting.

Table 3. Electrical conductivity of leachate of container-grown spiraea in response to different CRF products and rates after over wintering. Leachate was collected on April 7, 2009.

CRF	g	EC	CRF	g	EC	CRF	g	EC	CRF	g	EC
A	383	0.71	C	360	0.52	E	408	1.55	G	408	1.64
A	574	1.87	C	540	0.67	E	612	0.75	G	612	1.15
A	768	0.9	C	720	1.02	E	816	1.88	G	816	0.98
B	383	0.51	D	408	0.98	F	340	0.89			
B	574	1.07	D	612	1.12	F	510	1.34			
B	768	1.42	D	816	1.63	F	680	1.09			

Table 4: End of season foliar nutrient contents of container-grown spiraea in response to different CRF products and rates.

Treatments	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	B
	%					mg.L^{-1}				
Rep	0.13 NS	0.000 NS	0.006 NS	0.033 NS	0.003 NS	573 NS	37 NS	2531 NS	0.535 NS	2 NS
Fertilizer (F)	0.23**	0.007**	0.053*	0.044 NS	0.001 NS	2167*	157 NS	4668*	1.162*	16*
Rate (R)	0.62**	0.002 NS	0.013 NS	0.002 NS	0.001 NS	6533**	297*	10603**	1.396 NS	32**
F x R	0.02 NS	0.002 NS	0.017 NS	0.002 NS	0.000 NS	1177 NS	34 NS	285 NS	0.168 NS	3 NS
Fertilizer	**	**	*	NS	NS	*	NS	*	*	*
A	2.07 *d*	0.23 *cd*	1.51 *ab*	0.88	0.29	163 *ab*	37	161 *bc*	2.75 *ab*	29 *abc*
B	2.11 *cd*	0.23 *cd*	1.51 *ab*	0.88	0.30	144 *b*	39	151 *bc*	3.17 *a*	28 *bc*
C	2.30 *a*	0.27 *ab*	1.63 *a*	0.90	0.31	150 *b*	49	205 *a*	2.23 *b*	31 *a*
D	2.09 *cd*	0.29 *a*	1.53 *ab*	0.92	0.32	143 *b*	39	151 *bc*	2.48 *ab*	30 *ab*
E	2.43 *a*	0.25 *bc*	1.57 *ab*	0.91	0.31	185 *a*	48	181 *ab*	3.18 *a*	27 *c*
F	2.42 *a*	0.21 *d*	1.43 *b*	0.87	0.32	151 *b*	41	140 *c*	2.96 *a*	29 *abc*
G	2.21 *bc*	0.28 *ab*	1.65 *a*	0.93	0.31	142 *b*	42	148 *bc*	2.59 *ab*	31 *a*
Rate	**	NS	NS	NS	NS	**	*	**	NS	**
0.6	2.04 *b*	0.26	1.52	0.90	0.31	134 *b*	38 *b*	137 *b*	3.03	31 *a*
0.9	2.30 *a*	0.25	1.57	0.89	0.31	159 *a*	42 *ab*	172 *a*	2.75	29 *ab*
1.2	2.37 *a*	0.24	1.56	0.91	0.31	168 *a*	45 *a*	179 *a*	2.52	28 *b*
F x R	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

**, * Significant at $P \leq 0.01$ and $P \leq 0.05$, respectively; NS, not significant.
Means accompanied by common letters are not significantly different at $P \leq 0.05$ by Least Significant Difference (LSD) test.

to CRF product D and CRF product E though was comparable to CRF products A and B, were significantly higher than CRF product F.

Tissue K contents did not differ much between CRF products and ranged between 1.43 to 1.65%. However, CRF products C and G had greater tissue P contents than CRF product F and rest of the CRF products were comparable to all.

There were no differences in tissue Ca, Mg and Mn contents between CRF products and other micronutrients (Fe, Zn, Cu and B) though statistically showed some differences between CRF products, in terms of absolute amounts the differences were minimal except for some grater amounts of Zn in CRF product C.

Tissue P, K, Ca, Mg and Cu contents did not differ at different CRF rates however, did differ for N, Fe, Mn, Zn and B and in most cases rate 0.9 and 1.2 kg N/m^3 had similar and significantly greater contents compared to rate 0.6 except B. Where rate 1.2 kg N/m^3 had lower contents compared to rate 0.6 kg N/m^3.

DISCUSSION

This study compares the performance of seven selected controlled-release fertilizer (CRFs) products as determined by final growth of containerized spiraea as measured by top dry weight in particular, and by some other plant growth parameters (plant height and width), EC and pH. This study also quantifies amounts of NO_3-N leaching from container-grown spiraea under various CRF rates that potentially flows into the environment.

The results confirms that growth of spiraea occurred maximally with CRFs A, B and G and minimally with CRF F followed in an order by A, B, Ge" Ee" C> D> F (Fig. 1). CRF products A, B and G had about 30, 12 and 5% greater growths respectively over F, C and D. Growth with CRF product E was comparable to products A, B and G. Differences in tested CRF products in terms plant height and width though were marginal (but statically significant) however, minimum heights and widths of spiraea plant with CRF products D and C (Figs. 3.and 4) are in conformity of poor performance of these two products compared to others.

Better performance of CRF products A, B, G and poor performances of F and D seemed not to be related to the N contents of the products (as N contents were homogenized for all seven products before treatment application, Table 1) or to the release time/duration of the nutrients from the CRF prills. Rather it was related to the nutrient release pattern and thus nutrient availability to the plants during the entire growth period, from the beginning to up to first 6/7 weeks in particular. Our phenotypic observation (Tables 2a and 2b) and Nitrate-N release pattern over time of product F in particular (Fig. 5, 1.2 kg N/m^3) clearly supports this view.

Nursery production involves growing plants in pots filled with a nutrient free porous medium (usually partly composted bark, peat moss, and compost) and nutrient losses in leachate are an important component of the total non-used nutrients that negatively impact on plant growth (Huett, 1997, Lamhamedi et al., 2001). Therefore, efficient production of container-grown plants requires a fertilization program that will provide a constant and uniform level of nutrition throughout the production cycle according to the needs of the plants, extending for at least some time through the marketing period (Wilson et al. 2005). Controlled-release fertilizers, though are purposively prepared to provide all nutrients releasing over an extended period of time, have been seen to release in greater amounts during the beginning (Broschat, 1996; Huett and Gogel, 2000; Wilson et al., 2005), when plants are small and nutrient requirements are low. This is also evident in this study for all products except product F (Fig. 5) and our other studies as well (Chong et al., 2006). Higher leachate NO_3-N at the beginning of the growing period was probably due to the effect of higher initial nutrient release into the substrate during the first few weeks, without yet being balanced by plant uptake. Nevertheless, this trend is generally thought not to be in favour of good plant growth as it can readily exhaust the fertilizer and promote high salinity levels at this stage, which may limit plant growth (Jacobs et al., 2003, Goodwin et al., 2003), Wilson et al., 2005). In this particular study, NO_3-N contents in the leachate for product F for the first three weeks was negligible (about 1 mg•L^{-1}) whereas for products A, B and G it ranged between 14-about 40 mg•L^{-1} (thereafter the trends were almost similar), yet product D had the lowest plant growth. The explanation lies in the fact that due to low NO_3-N contents in the leachate (thus low nutrient release from the CRF prills and low nutrient availability to the plants) spiraea plants grown with product F suffered initial establishment. Our visual obviation supports this as product F at all three rates (0.6, 0.9 and 1.2 kg N/m^3) were observed with yellowish leaves, and reduced growth than other CRF products under study indicating clear starvation of plants with this particular product. However, after about six weeks of potting, the plants though recovered from starvation and end of season phenotypic scoring and tissue analyses showed that product F had high phenotypes scores and the highest N contents and other nutrients in sufficient levels, the nutrient deficiency plants had to suffer during the first 3-4 weeks of initial establishment, could not recover during the reminder period of the study. These results suggest that for container production with nutrient-free porous medium, there should be sufficient nutrient supply for better initial plant establishment. Though, apparently it seems to be nutrient wastage. If product F could be rectified and the nutrient release could be increased a bit (about 15-20 mg•L^{-1} NO_3-N in the leachate) also during the initial 3-4 weeks, the performance of this product could be similar to other products in this study.

Spiraea growth increased linearly with increased CRF rates without any sign of isotherm (Fig. 2, average over all fertilizer products) indicative of not achieving maximum growth even at 1.2 kg N/m^3 (maximum rare tested) for most CRF products. However, the quadratic response surface model for individual CRF products revealed that the optimum rates for CRF products A, B, C, D, E, F and G were respectively 1.5, 1.3, 1.2, 2.7, 1.7, 1.2 and 1.1 kg N/m^3 for maximum spiraea growth.

The NO_3-N concentration in the leachate increased with increasing CRF rates as expected. In all CRF products, it reached its peak within 4-6 weeks, then a plateau for few more weeks and reducing gradually thereafter and indicated the leached amounts were within acceptable limits even at 1.2 kg N/m^3. Throughout the growing season, the medium EC and pH levels of all fertilizer treatments were within values recommended for nursery crops (Mathers 2000).

CONCLUSIONS

This study reconfirms that performance of CRF products A, B and G were better and performances of products F and D were poor in terms of spiraea growth. Performances of products C and E were intermediate. Lack of interaction between fertilizer treatments and rates for any of the plant parameter measured and nutrients made this conclusion straight forward and precise. The optimum rates for CRF products A, B, C, D, E, F and G were respectively 1.5, 1.3, 1.2, 2.7, 1.7, 1.2 and 1.1 kg N/m^3 to achieve maximum spiraea growth. However, this needs to be confirmed from field trial with rates below and above these rates as in this study maximum 1.2 kg N/m^3 rate was tested. Sufficient nutrient availability appeared to be essential during the initial stages of plant growth for better plant establishment. Formulation of product F needs to be rectified to increase its field performance increasing the nutrients releases from its prills also during the initial 3-4 weeks of application.

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