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## Session 3.5: Options and Benefits: Learning from Case Studies

# FERTILITY OPTIONS FOR GREEN ROOFS.

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**Abstract**

During establishment and periodically throughout their life, green roof systems require some minimal maintenance. This maintenance may include plant replacement, biomass removal, weeding, irrigation, and fertilizer applications. Just like at-grade landscape systems, planted rooftop landscapes have fertility requirements - at least initially. We have evaluated the performance of four green roof fertility options since September 2005 in four different growth media selections and with three different *Sedum* species. During the establishment period (first 18-months of the study) plants fertilized with IBDU exhibited the greatest diameter growth and, therefore, the greatest roof coverage. Unfertilized green roof systems exhibited unsatisfactory plant growth and performance during this establishment period and were replaced in spring 2007 with new plants and Nutricote fertilizer. Our evaluations in spring 2008 indicate that roof coverage of plants receiving one application of Osmocote fertilizer in 2006 and again in 2007 exceeds that of plants receiving similar applications of IBDU. Further, plants established in 2007 and fertilized with Nutricote have greater roof coverage than plants established two years prior and fertilized with IBDU both years. Finally, we did not fertilize any of these green roof systems in 2008 and all experimental units have maintained sufficient plant diameter growth and roof coverage throughout this growing season. Our data indicates that green roof systems require fertilizer at establishment and that after two years (establishment) green roof systems may not require annual fertilizer applications.

**Introduction**

As with any living environmental system, it is extremely important to factor care and maintenance issues into design decisions before any green roof plant installation takes place (Wegscheid 2009). Therefore, fertilizers are a critical component to provide essential nutrients for plant survival, growth, and sustainability of green roof systems. The rate and frequency of fertilizer application is important – both for plant survival and performance of the green roof (Emilsson et al. 2007; Rowe et al. 2006) and to reduce the possibility of downstream nutrient contamination (Berndtsson et al. 2008; Retzlaff et al. 2008). The requirement for fertilization is determined during the growth media and plant selection process (Wegscheid 2009) when the green roof is first designed – long before the installation. For example, growth media with high organic matter content may not require as much fertilization as growth media with less than 20% organic content. Further, *Sedums* used in most green roof applications are adapted to mineral soils with minimal nutrient requirements and may not be as demanding as other species for additional nutrient applications. Just deciding at installation to "toss" a little fertilizer on the roof is an option that can lead to disastrous outcomes; (1) nutritional deprivation and loss of green roof plants, (2) fertilizer burn/injury (Gibbs 2007; Retzlaff et al. 2008), and (3) downstream water contamination (Berndtsson et al. 2008; Retzlaff et al. 2008a).

As stated previously, green roof plants (plugs) are usually fertilized at the time of planting and then approximately once a year for some period and it is generally recognized that acceptable plant growth occurs using an application rate of 50 g/m$^2$ when using *Sedums* (Rowe et al. 2006). This level of fertilizer allows for normal plant growth, while also discharging a minimal amount of nutrients into runoff. Most applications typically use a controlled-release fertilizer (Emilsson et al. 2007; Rowe et al. 2006) or a conventional fertilizer (Emilsson et al. 2007). However, it has been noted that conventional fertilizers may result in high nutrient concentration in green roof runoff water (Emilsson et al. 2007). Excess use of any type of fertilizers in a green roof project can result in runoff contamination (Berndtsson et al. 2008; Retzlaff et al. 2008a).

Therefore, besides controlling green roof costs, a minimal amount of fertilizer should be utilized so as to prevent damage to green roof plants and leaching of nitrogen, phosphorus and other nutrients in storm water runoff. Since the development of green roof technology in the United States and the long-standing FLL practices in Europe, there have been changes in commercial fertilizer blends/composition that may benefit green roof applications. For instance, there is a Nutricote 720 that is marketed with a 720 day release-rate – this may be a viable option for minimal nutrient release that may provide optimum plant growth and no downstream water quality issues. On our research green roof, we previously described a fertilizer injury incident in August 2005 (Retzlaff et al. 2007) that lead us to this current series of fertility investigations. We established a green roof fertility experiment on the research green roof on the Engineering Building at Southern Illinois University Edwardsville in September 2005 and report the result of our ongoing three-phase project here. Data in this project has been collected and analyzed through November, 2008. Our initial hypothesis (Phase I) was to evaluate whether fertilization at green roof establishment was necessary and which type of (two) controlled-release fertilizer may facilitate a dense vegetative cover during the initial establishment period. In the second year of the project (spring 2007), we added a third controlled-release fertilizer (replacing the no-fertilizer treatment – Phase II) and followed Phase II with no fertilizer application at all in 2008 (Phase III) and the results of this three-phase project are inciteful.

## Materials and Methods

Green Roof Blocks™ were arranged in a completely randomized design with three replications in phase I of this experiment. Green Roof Blocks™ are constructed of anodized aluminum and are 2 ft x 2 ft with 10 cm growth media depth and in our project were placed directly on the rooftop surface (EPDM membrane) of the Engineering Building at Southern Illinois University Edwardsville. On September 20, 2005, 540 *Sedum spp*. plugs (species described below) were planted into 108 Green Roof Blocks™. Each Green Roof Block™ contains five plugs of the same *Sedum* species randomly assigned to different growth medium and fertilizer applications (Figure 1 and 2).

Four different growth media were used: Arkalyte (heat-expanded clay), Hadite (heat-expanded slate), Pumice, and Lava, each with 3/8-inch aggregate diameter cobble. Each of the four inorganic growth media was blended with organic matter, composted pine bark, for an overall inorganic:organic ratio of 80:20. Each Green Roof Block™ was filled to a 10 cm depth.

Three different fertilizer treatments were used initially (all applied at the time of planting and once again in March 2006 in Phase I): Isobutylidene diurea (IBDU – a nitrogen-based fertilizer, 3.7 grams was applied to each individual plant); Osmocote (N-P-K ratio 15-9-12, 5.3 grams was applied to each individual plant); and a No-Fertilizer treatment (labeled control). Nutrients from IBDU (Figure 3) are gradually and consistently released through water or microbial contact through slow hydrolysis. We used a very large size IBDU formulation in order to increase the length of time that this product would be available to the green roof plants in this study. The Osmocote we chose is a controlled-release fertilizer composed of water-soluble nutrients (Figure 3). Water passes through the Osmocote membrane, eventually causing enough internal pressure to disrupt the membrane and release nutrients. The rate of release of nutrients can depend on the coating thickness and is also highly dependent on temperature. Therefore we initially evaluated two fertilizers that exhibited control-release properties driven by water or microbial activity (IBDU) and thermal/water (Osmocote) exposures.

Three different *Sedum* species were evaluated in Phase I of the project. Initially these were *Sedum hybridum immergrauch*, *Sedum spurium*, and *Sedum sexangulare*. Sedums were evaluated because of their tolerance to high temperature and drought conditions. In Phase II and Phase III of this project, after the winter of 2005-2006, *Sedum hybridum immergrauch* was replaced with *Sedum kamtschaticum*. All of the *Sedum hybridum immergrauch* plants suffered severe winter injury and did not survive – unrelated to the fertilizer project (a winter shading issue; Retzlaff et al. 2008).

Following a second growing season (2006) and over-wintering period (winter 2006-07), in April 2007 we replaced all of the plants in the Non-Fertilized (control) treatment Green Roof Blocks™ with new plants of the appropriate *Sedum* species (*Sedum spurium, Sedum kamtschaticum,* and *Sedum sexangulare*) and fertilized the previous non-fertilized (1$^{st}$ application of fertilizer in these green roof models) treatment Green Roof Blocks™ with Nutricote 540 (18-6-8; 3.5 g/plant – a thermally controlled-release fertilizer that was new on the market and is advertised as a 540-day release product). We also re-fertilized the Osmocote and IBDU green roof models (at the same application rate as in September 2005 and March 2006 – 3$^{rd}$ fertilizer application) – Phase II of this experiment.

In April 2008, we did not fertilize any of the experimental green roofs to evaluate longevity of fertilizer application – Phase III of this experiment. In April and November 2008 we evaluated plant roof coverage of green roof models that had not been fertilized since April 2007.

The experimental design in this three-phase fertility project was a factorial experiment (4 growth media x 3 sedum species x 3 fertilizers = 36 treatments) with three replications (108 Green Roof Blocks™) in a completely randomized experimental design. Each of the experimental phases (Phase I – Sept. 2005 to April 2007; Phase II – April 2007 to April 2008; Phase III – April 2008 to November 2008) was analyzed separately as described below.

Data in this project was collected on a monthly basis with the exception of the early establishment period and winter months. During the early establishment period, which was from September 20 to November 17, 2005, data was collected twice a month. During the winter months (2005-06; 2006-07; 2007-08) no data was collected because of insufficient plant growth (and freezing conditions on our roof).

Percent roof coverage by plants was evaluated using a circle coverage grid (each circle is 3.8 cm in diameter – 36 circles per coverage grid) in four quadrants in each Green Roof Block™. The number of bare (no-plants) circles in each quadrant was recorded and used to calculate the percent roof coverage of each block (Figure 4). To be counted as bare, each circle must have at least 90% of its area without vegetation. We divided the number of "covered" circles by 36 and multiplied by 100 to obtain the percent roof coverage at time of measurement. We also measured the diameter (in two perpendicular directions) of each plant at the same time interval as plant roof coverage measurements using clear plastic 45 cm rulers.

Collected data was input after each measurement into an Excel spreadsheet, which was then formatted for use in SAS. All recorded data has been analyzed using SAS Version 9.1 statistical software to determine if green roof growing media, *Sedum* species, or fertilizer treatment alters green roof performance (analysis of variance in a factorial experiment for a completely randomized design, $\alpha < 0.05$). In this report, we focus on the fertility responses.

Once a treatment difference was indicated by ANOVA for a completely randomized design in each Phase (I, II, or III), a Tukey's post-hoc test was used to determine differences between treatments.

## Results and Discussion

### *Phase I*

Plants that received no fertilizer and those fertilized with Osmocote showed no difference in roof coverage at the end of the early establishment period (September 20 – November 17, 2005) (Figure 5). Plants fertilized with IBDU showed the most roof coverage (Figure 5) and largest plant diameter measurements (Figure 6) beginning on October 18, 2005 and during the rest of the early establishment period (through November 2005).

During and following the winter of 2005-06, noticeable winter injury was observed for a large number of plants – all one *Sedum* species (Retzlaff et al. 2008). We lost 100% of the *Sedum hybridum immergrauch* because our roof is shaded for a large part of the winter season and this species is known to be intolerant of winter shade. During this first winter there was no difference in survival between fertilizer treatments, with average survival being close to 60% (Figure 7). This level of survival is likely not acceptable for a commercial green roof project. Our late planting date (September 20, 2005) and the fact that our roof went into the "shade" not long after planting likely contributed to this low survival rate. In a previous study, late fall plantings clearly did more poorly that spring plantings (Getter and Rowe 2007). Early spring re-plantings in the following years of this project and other plantings in other experimental research projects on this research green roof have much higher survival rates following the first winter (data not shown).

Beginning in May 2006 (following a 2nd fertilizer application in March 2006 and replacement of the *Sedum hybridum immergrauch* with *Sedum kamtschaticum*) and throughout the rest of the 2006 growing season, plants fertilized with Osmocote showed the most roof coverage (60%) (Figure 8) as well as the greatest plant diameter (Figure 9), while the non-fertilized plants showed the least (Figure 8 and 9). The guidelines developed by the FLL state that "a green roof should have a projective cover of at least 60% one year after establishment" (FLL, 2002) and we achieved this guideline with the Osmocote fertilizer treatment. We concluded at the end of this growing season (the end of Phase I) that No-Fertilizer is not an option for establishment of a green roof. Non-fertilized plants, while still surviving, were not adequately covering the roof. It appears that Osmocote controlled-release fertilizer (thermal/moisture release) may possibly be the best choice as a "starter" fertilizer even though during the first sixty days the IBDU application out-performed the Osmocote application. Solid forms of fertilizer that slowly release nutrients during water contact or through microbial activity are generally considered to be effective for green roof application (Wegscheid 2009). However, while our initial data support the slow- or controlled-release rate, a thermally activated control-release fertilizer (Osmocote) has outperformed one that is released by water or microbial activity (IBDU).

***Phase II***

In June 2007, plant roof coverage of the green roof models treated with Osmocote in September 2005, March 2006, and April 2007 far exceeded the roof coverage of the green roof models treated with IBDU and Nutricote (Figure 10). In November 2007, plant roof coverage of the green roof models treated with Osmocote in 2005, 2006, and 2007 also far exceeded the roof coverage of the green roof models treated with IBDU and Nutricote (Figure 11). However, by November 2007 the plant roof coverage in the green roof models treated once with Nutricote in April 2007 exceeded the plant roof coverage in the green roof models treated with IBDU in 2005, 2006, and 2007. This is quite interesting as IBDU would be released with any rainfall or microbial activity and was noted earlier in Phase I to be the best for early growth. We observed, in the long-term, other controlled-release products like Osmocote and Nutricote (with temperature dependent release) are superior to water-released IBDU. The use of controlled release fertilizers is aimed at maintaining nutrient availability in the green roof growth medium that may meet plant nutrient requirements over an extended period of time (Emilsson et. al 2007). In our study, after a partial growing season (2005) and two full growing seasons (2006 and 2007), it is clear that Osmocote is providing adequate nutrients to meet nutritional requirements as we have obtained sufficient plant roof coverage.

***Phase III***

We did not re-fertilize any of the green roof models in spring 2008 to begin an experiment to evaluate when fertilizer inputs would no longer be necessary to maintain the plant community a green roof (experimental or commercial application). In April 2008, plant roof coverage of the green roof models treated with Osmocote was greater than those treated with IBDU or Nutricote (Figure 12). Further, those treated with Osmocote in September 2005, April 2006, and April 2007 had a plant roof coverage of approximately 60% - maybe not adequate for a commercial green roof, but useful in this study. We found in November 2008, eighteen months since the last fertilizer application (April 2007) that the plant roof coverage of the green roof models treated with Osmocote was 80% and much greater than those treated with Nutricote (43%) and IBDU (29%) (Figure 13). Apparently, three applications of Osmocote at the rate we chose are sufficient to generate and maintain growth for at least eighteen months following the last fertilizer application. It remains to be seen if adequate plant roof coverage will still be maintained on this experimental green roof and whether additional fertilizer applications will be necessary. Based upon the advertised extended release rate of the Nutricote (540 days), it may be that plant roof coverage will still continue to develop in green roof experimental models fertilized with this product. It is likely that a green roof fertilized with IBDU would need additional applications to achieve adequate green roof growth. The use of fertilizer products that maintain plant nutrient requirements over long periods reduces the cost of maintenance associated with repeated, yearly applications on a green roof and may reduce nutrient losses to downstream water supplies (Shaviv 2001). At least in our study, we have demonstrated that controlled-release fertilization on a green roof with some products is a viable option for fertility maintenance.

## Conclusions

This three-phase green roof fertility project has provided affirmation of the importance of choosing a fertility maintenance plan prior to green roof installation. In addition, this project also indicates the importance of maintaining that plan during at least the first three years of a green roof life-span. First, it is very clear that No-Fertilizer application at planting (establishment), no matter how healthy and robust the green roof plants look when delivered to the site, is not a viable option. In this project, this "treatment" was a complete failure with three *Sedum* species and four growth media blends – likely the same outcome in all other media blends and species choices. Second, while we obtained the fastest establishment in the first sixty days of our project with a fertilizer (IBDU) that is released by microbial activity or water, this too was not sufficient to maintain healthy plant growth and development through the life of our project. Finally, both Osmocote and Nutricote (fertilizers that are thermally activated) provided the best plant growth and roof coverage in this study. This level of plant roof coverage was maintained for an extended period (18 months) following a third application of Osmocote or only one application of Nutricote. How long this green roof will remain viable now that we have stopped fertilization remains to be seen – we will follow this and report back.

Two fertilizer questions were not addressed directly in this study, but should be mentioned are plant hardiness and nutrient runoff. Excessive fertilization can contribute to both problems. Plants that have been excessively fertilized are typically not hardy (Jauch 1993), but this does not appear to be an issue in our study as we have no plant losses that could be attributed to over-winter or drought conditions (and we have experienced both in this long-term study). Further, a green roof that receives excessive fertilization can become a source of downstream nutrient contamination (Berndtsson et. al. 2008), but in a water quality green roof study at our field site with the same rate of fertilizer application with IBDU we previously reported no downstream water quality issues (Retzlaff et al. 2008).

A fundamental part of the success of an extensive green roof is the establishment and development of adequate plant survival and roof coverage (Emilsson and Rolf 2005). Besides the choice of growth media and plant species, fertilizer choice is critically important and can add headaches and unnecessary costs to a green roof project. Our data above indicates to us that possibly a combination of an initial fertilization with a product that is readily available (water or microbial release), followed by an application later in the 1$^{st}$ season or in the second year with a fertilizer that is more long-lasting (thermally released) might be a great management option. We will be also exploring this combination in future studies.

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| | Replicate I | | | Replicate II | | | Replicate III | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |
| | PSO | LIC | | LSC | PIO | | AAO | LSI | |
| | HSI | PAI | | PAC | AAC | | LIC | HAI | |
| | HII | LII | | LIC | HIC | | PSI | PII | |
| | PAC | ASI | | HSI | LAO | | AAC | HAC | |
| | HSO | AAC | | AAO | AIO | | LAO | AIO | |
| | HIC | LSC | | PAI | PAO | | PSO | LIO | |
| | AIO | LSO | | PSC | LSI | | PAO | HSC | |
| | PIO | ASC | | HIO | AAI | | HII | LSC | |
| | HSC | LAI | | HII | HAI | | LAI | HIC | |
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| | PIC | AAI | | AIC | PIC | | PSC | PAI | |
| | LAC | HAI | | LSO | LII | | LSO | HAO | |
| | PSC | AII | | LAC | HSO | | PAC | HSI | |
| | PAO | HIO | | HSC | HAC | | HSO | AII | |
| | LIO | AAO | | ASC | ASI | | LAC | ASO | |
| | PII | AIC | | LAI | PSI | | HIO | ASC | |
| | HAO | LAO | | ASO | HAO | | LII | PIC | |
| | ASO | HAC | | AII | LIO | | AIC | PIO | |
| | LSI | PSI | | PSO | PII | | ASI | AAI | |
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Figure 1: Diagram of Phase I of the project layout, which was installed in a completely randomized design on the roof of the Engineering Building on the SIUE Campus on September 20, 2005.

**Legend for Figure 1**

Phase I

1st letter - Growth Media

- P=Pumice
- L=Lava
- A=Arkalyte
- H=Hadite

2nd letter - *Sedum* species

- S=*S. spurium*
- A=*S. sexangulare*
- I=*S. hybridum immergrauch* (replaced with *S. kamtschaticum* in April 2006)

3rd letter - Fertilizer Treatment

- C=Control (No-Fertilizer)
- I=IBDU
- O=Osmocote

In Phase II, the No-Fertilizer treatment was replanted with the above species and Nutricote 540 was applied at time of planting in April 2007.

In Phase III, no fertilizer applications were made in the spring of 2008.

Figure 2: Picture of Phase I of the project layout, which was installed in a completely randomized design on the roof of the Engineering Building on the SIUE Campus on September 20, 2005.

Figure 3: Picture of IBDU Fertilizer, which is a nitrogen-based fertilizer (left) and picture of Osmocote fertilizer, which is a controlled-release fertilizer (right), applications.

Figure 4: Undergraduate students recording roof coverage measurements with circle dot-grid. (These measurements were recorded twice a month during the early establishment period and once a month throughout the project).

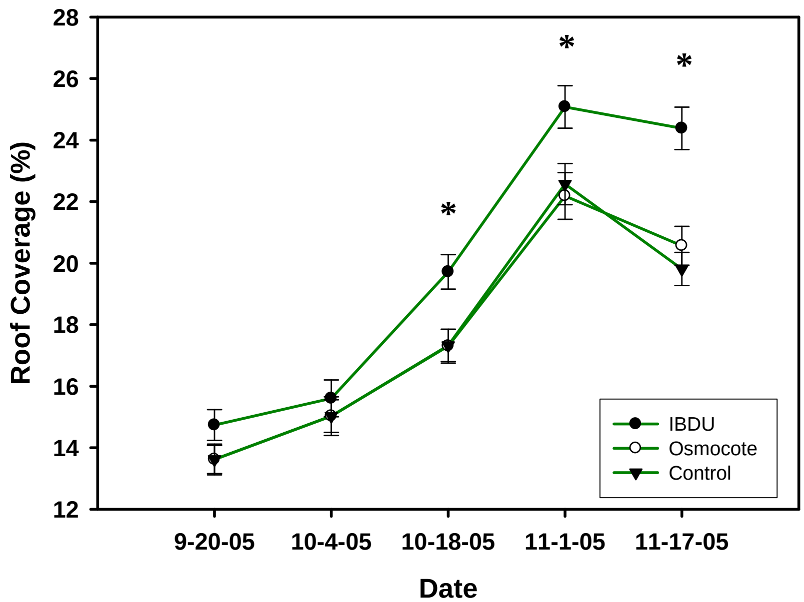


Figure 5. Plant Roof coverage by fertilizer treatment for the early establishment period during Phase I (* Indicates a difference between one or more means, $\alpha<0.05$; Error Bars represent $\pm1$ SE). (3.7g/plant of IBDU and 5.3g/plant of Osmocote was applied September 2005; No-Fertilizer = Control) (n=144).

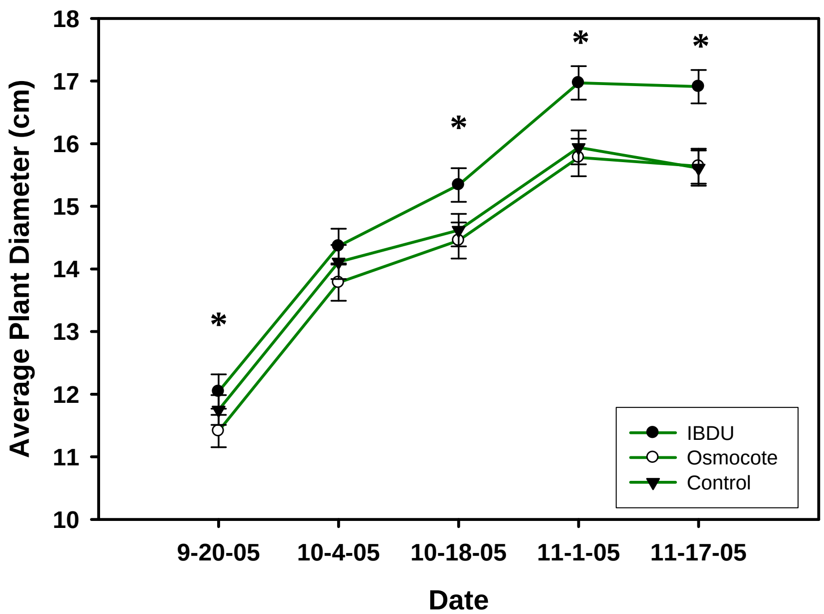


Figure 6. Average plant diameter by fertilizer treatment for the early establishment period during Phase I (* Indicates a difference between one or more means, $\alpha<0.05$; Error Bars represent $\pm 1$ SE). (3.7g/plant of IBDU and 5.3g/plant of Osmocote was applied September 2005; No fertilizer = Control) (n=180).

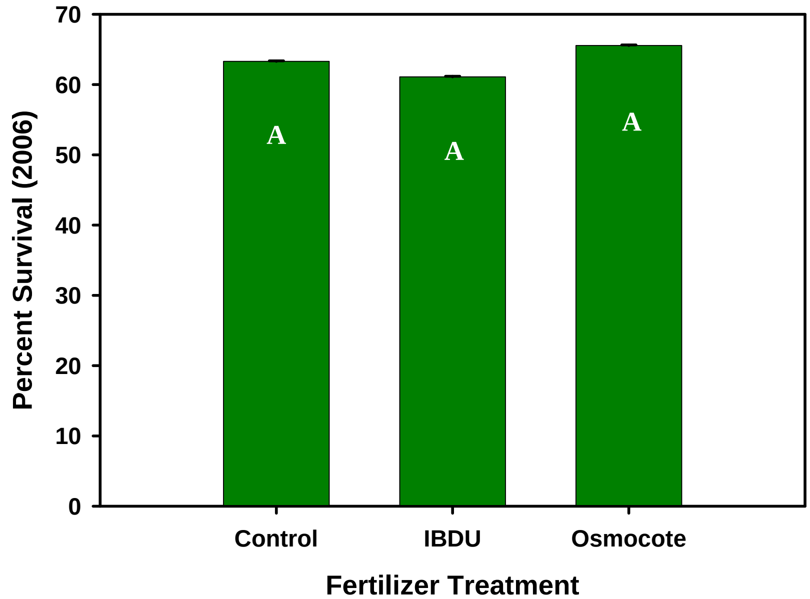


Figure 7. Plant survival after 2005-06 winter season (recorded in March 2006) (Different letters in bars represent means that are different, $\alpha$<0.05; Error Bars Represent +1 SE) (n=180).

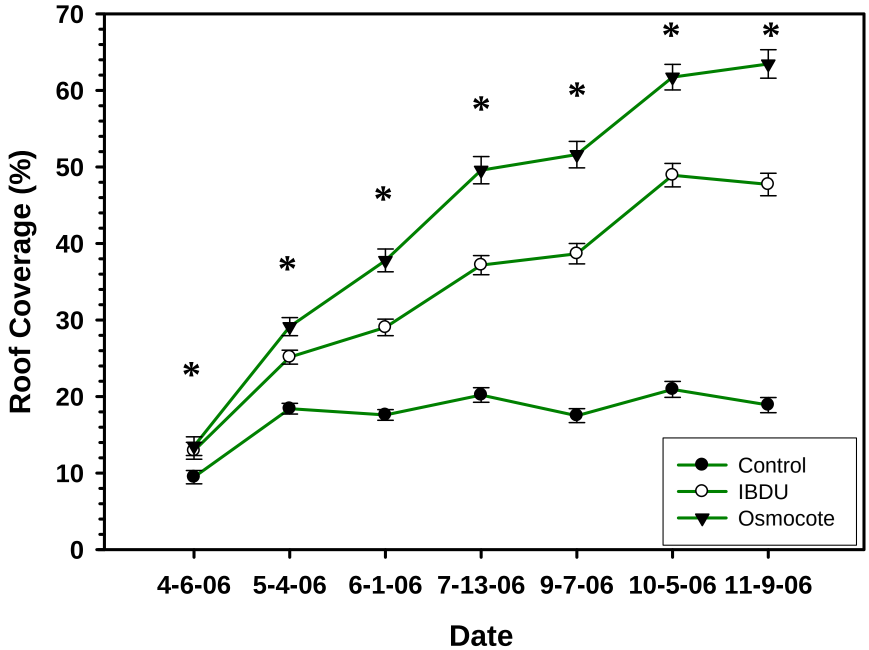


Figure 8. Plant roof coverage by fertilizer treatment for the 2006 growing season (* Indicates a difference between one or more means, $\alpha<0.05$; Error Bars represent $\pm1$ SE). (3.7g/plant of IBDU and 5.3g/plant of Osmocote was applied April 2006; No fertilizer = Control) (n=144).

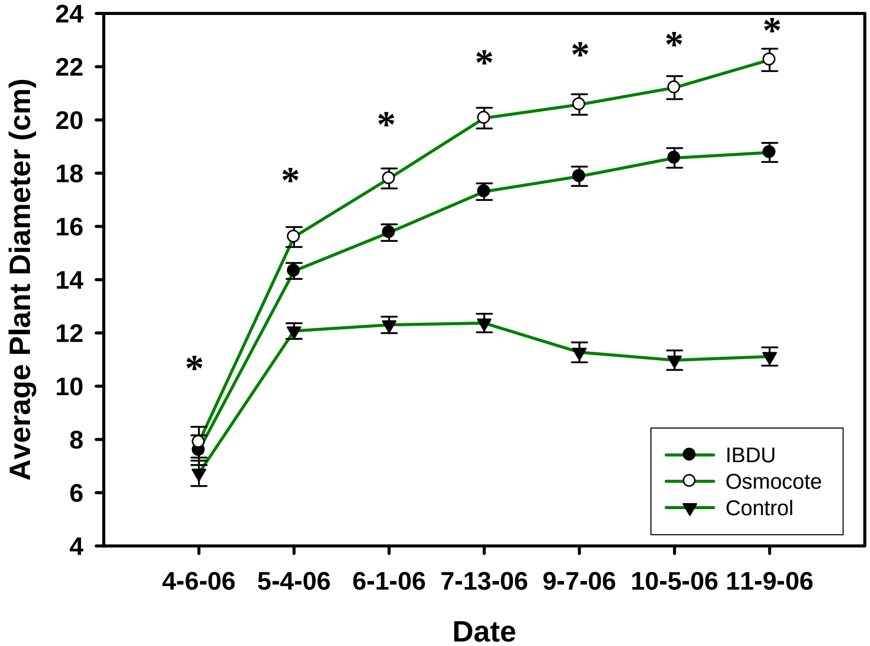


Figure 9. Average plant diameter by fertilizer treatment for 2006 growing season (* Indicates a difference between one or more means, $\alpha<0.05$; Error Bars represent $\pm$1 SE). (3.7g/plant of IBDU and 5.3g/plant of Osmocote was applied April 2006; No fertilizer = Control) (n=180).

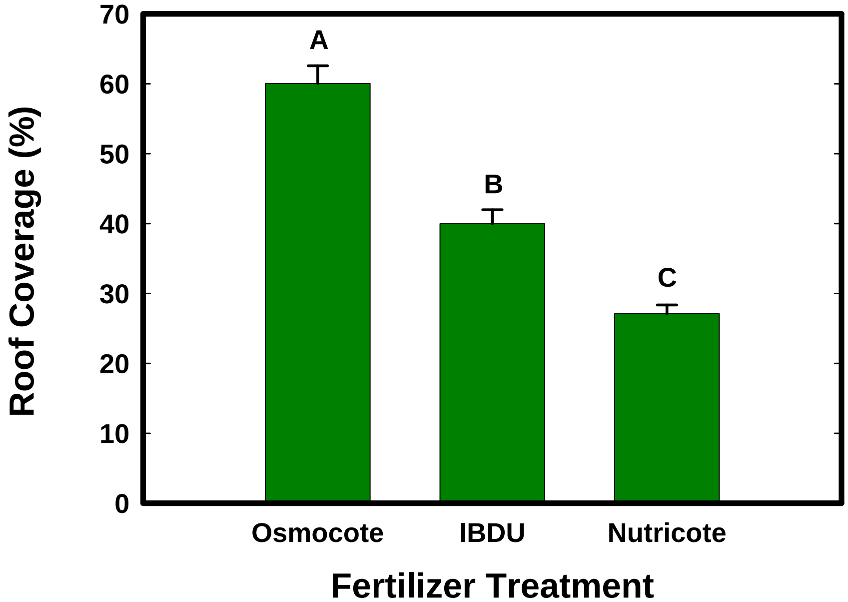


Figure 10. Plant roof coverage by fertilizer treatment in June 2007 (Different letters above bars represent means that are different, $\alpha<0.05$; Error Bars Represent +1 SE). (3.7g/plant of IBDU, 5.3g/plant of Osmocote, and 3.5g/plant of Nutricote was applied April 2007) (n=144).

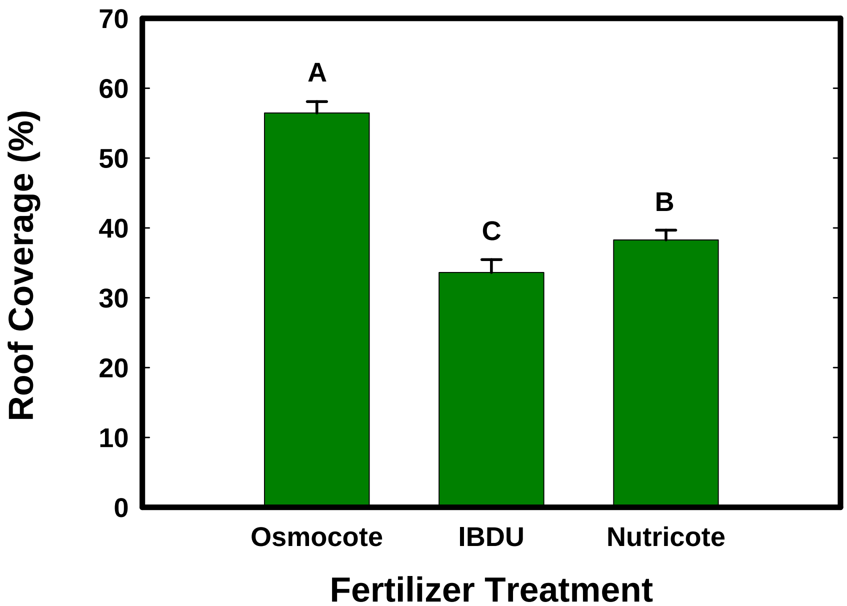


Figure 11. Plant roof coverage by fertilizer treatment in November 2007 (Different letters above bars represent means that are different, $\alpha<0.05$; Error Bars Represent +1 SE). (3.7g/plant of IBDU, 5.3g/plant of Osmocote, and 3.5g/plant of Nutricote was applied April 2007) (n=144).

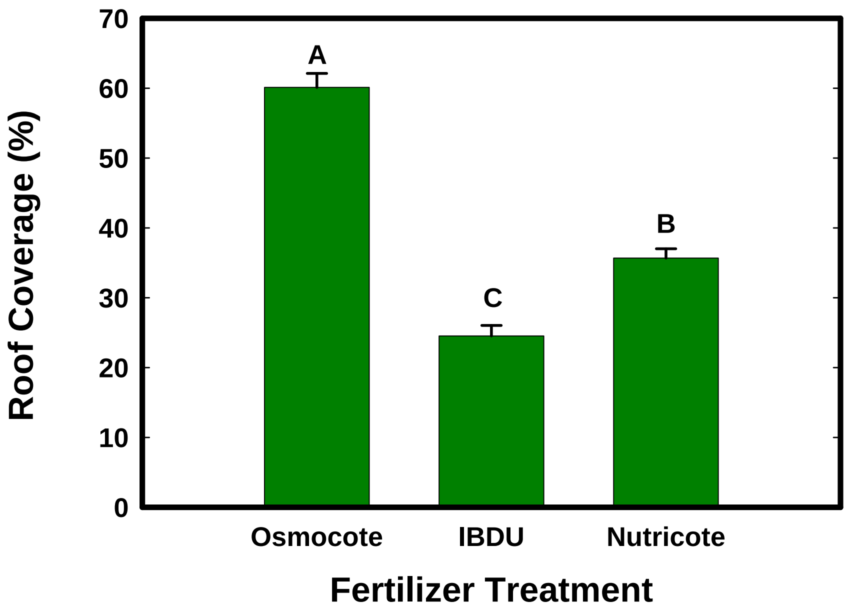


Figure 12. Plant roof coverage by fertilizer treatment in April 2008 (Different letters above bars represent means that are different, $\alpha<0.05$; Error Bars Represent +1 SE). (3.7g/plant of IBDU, 5.3g/plant of Osmocote, and 3.5g/plant of Nutricote was last applied April 2007) (n=144).

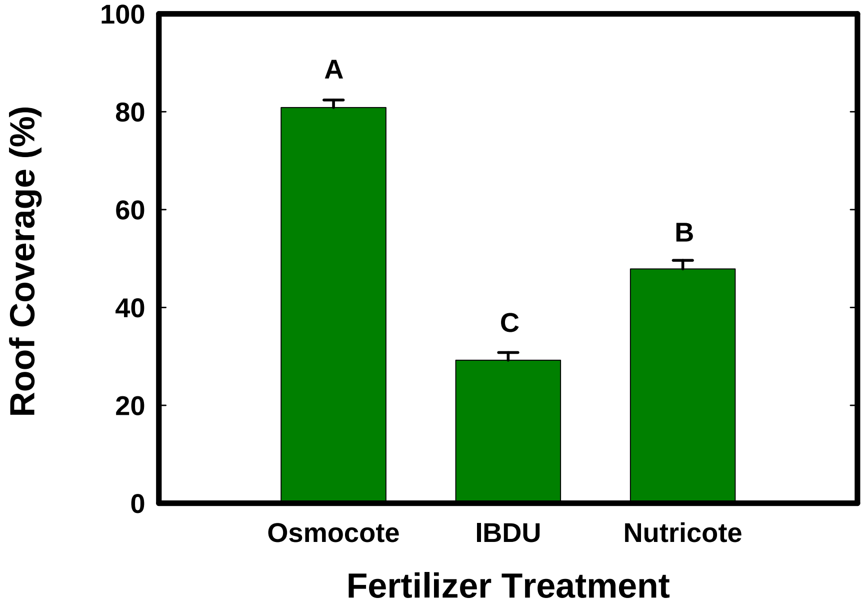


Figure 13. Plant roof coverage by fertilizer treatment in November 2008 (Different letters above bars represent means that are different, $\alpha<0.05$; Error Bars Represent +1 SE). (3.7g/plant of IBDU, 5.3g/plant of Osmocote, and 3.5g/plant of Nutricote was last applied April 2007) (n=144).