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Agro-ecosystem Approach to Sustainable Biofuels Production via the Pyrolysis-Biochar Platform

University of Minnesota Extension Master Gardener CenUSA Biochar Demonstration Gardens 2012-2015

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Abstract

Soil serves as the foundation of all gardens, and thus incorporating beneficial amendments before planting is of the utmost importance to a healthy, productive crop. Increased interest and research in biomass and biofuels has promoted the use of biochar, a coproduct of the pyrolysis process, as one amendment to improve soil health. Urban soils, the site of many home and community gardens, can be carbon-poor, so we wondered if biochar would benefit home gardeners and grow more productive plants. Soils at four demonstration sites in Minnesota were amended with hardwood biochar. With the help of Extension Master Gardener volunteers, we grew, harvested and measured common garden crops over four years to see if those grown in biochar-amended soils were more productive. Variables in weather, crops and volunteer interpretation of data did not provide conclusive results. However, the poorer soils amended with biochar showed some increase in soil pH and percent organic matter, and clay loam soils were less compacted. Most crop yields showed improvement over the four years; however, we believe these increased yields were likely affected by a combination of factors (rainfall, air temperatures) and cannot be directly attributed to the addition of biochar.

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Introduction

From 2012-2016, eight Midwestern universities collaborated under the name CenUSA Bioenergy to research the potential for growing and harvesting biomass on marginal agricultural lands to be processed for biofuel, which would result in less U.S. dependence on foreign oil, reduced greenhouse gas emissions and increased local renewable energy. Pyrolysis, the process used to extract plant oils from biomass, produces a carbon-based coproduct called biochar. Similar to other charcoal products, biochar is distinctive in that it is intentionally applied to soils to improve soil health, promote plant growth, sequester carbon, increase microbial activity, etc. (Biederman & Harpole, 2013; Lehmann & Joseph, 2009). CenUSA Bioenergy collaborators hypothesized that if biomass production on marginal lands and the production of biofuel proved economically and logistically viable for landowners, the availability of biochar as a retail product would increase.

From 2012-2015, University of Minnesota Extension Master Gardeners (EMG) partnered with Extension professionals to develop and maintain four demonstration gardens to investigate the effects of granular hardwood biochar at the rate of 0.5 and 1 lb/sq ft as a soil amendment to answer the question, "Is biochar beneficial and suitable as a soil amendment for home gardens?". Similar sites were established at three sites in Iowa; however, since they were managed with different methods, only Minnesota results are reported here.

Seven common vegetable garden crops were selected: basil, beans, cucumber, kale, tomatoes, potatoes and peppers. Additional vegetables and ornamental plants were also grown, but are excluded from this report due to crop failure or lack of significant data in growth or yield. Plant growth and yields were measured each year with the results varying by location and crop. Kale showed the most consistent yield increases when 1lb/sq ft biochar was used. Basil mostly showed decreases in harvest weight from biochar amended plots. Some of the other vegetable crops showed increased yields with biochar.

Biochar improved organic matter and pH at the sites with acidic sandy soils. The sites with silt-loam soil did not show consistent changes in organic matter or pH. EMGs who volunteered on the project reported improved soil tilth and reduced compaction in biochar treatments. Specific increased yields could not be attributed solely to biochar amendments in this study.

Volunteer recruitment, training and outreach materials

Recruitment, training and educational materials were created by Extension staff to communicate the roles and responsibilities to the volunteers. EMGs were given an overview of the CenUSA Bioenergy research project to gain an understanding of how their volunteer role fit into the larger scope of the project. Dr. Kurt Spokas, USDA-ARS Soil and Water Management Unit, and adjunct professor in the Department of Soil, Water and Climate at the University of Minnesota developed a webinar, "Biochar, What is it?" that informed the EMGs about the properties and value of biochar as a soil amendment. Detailed instructions were provided for EMGs on planting and best gardening practices for the specific crops utilized at the demonstration gardens (Table 1).

Key volunteerism priorities for this project included the freedom to volunteer, being prepared with the skills needed to complete the work, and support from a community of staff and other volunteers (Frendo, 2013). EMG leaders were recruited with specific responsibilities of volunteer scheduling, monitoring data collection and record keeping. EMGs trained onsite learned planting methods including crop rotation, thinning and pruning, staking, irrigation, integrated pest management (IPM) and sanitation. An online data collection system was developed to record plant height / width and harvest weight, and general observations about plant performance and health (growth, leaf color, pest issues).

Interpretive signage at the demonstration gardens provided walk-by learning opportunities for the public about the biochar research and bioenergy project. The intent of the signage and respective demonstration gardens was to increase public curiosity and knowledge gained (Glen et al., 2013). A great deal of effort went into creating outreach materials to educate EMGs and for their use in educating the public.

Table 1. Volunteer recruitment, training and outreach materials developed

Title	Authors	Format	Access
U of M scientists, Master Gardeners part of team to analyze biofuel production, land use	J. Christensen, Communications, U of MN Extension	Press release	Jan. 2012
EMG Biochar Project Volunteer Manual (Application; position descriptions; data collection instructions; data collection worksheet)	L. Davenport-Hagen EMG Program Coordinator Biochar Demonstration Garden Project Manager, U of MN	Manual	2012-2015 Distributed annually to volunteers
Biochar Demonstration Gardens and Recruitment Overview	L. Davenport-Hagen and J. Weisenhorn Associate Extension Professor and Extension Educator, U of MN	PowerPoint presentation	2012-2015 Presented in person to 450 EMGs in six counties
Biochar, What is it?	K. Spokas, USDA-ARS, Soil and Water Management & Adjunct Professor, Department of Soil, Water and Climate, U of MN	PowerPoint presentation	2012-2015, Online
Flower data reporting form	L. Davenport-Hagen	Google form	2012-2015, Online, EMG leaders only
Vegetable data reporting form	L. Davenport-Hagen	Google form	2012-2015, online, EMG leaders only
Dirt-O-Rama Exhibit	L. Davenport-Hagen, J. Weisenhorn, Sandy Tanck, Manager of Interpretation & Public Programs, MN Landscape Arboretum	Demonstration garden, 1-pg flyer, online	Exhibit, Summer 2012

Biochar, bio-benefits? Researchers and Extension Master Gardeners team up to evaluate the benefits of a sustainable biofuels system	B. Byers, CFANS Communications, U of MN	Article, CFANS *Solutions*	Sep. 2012, online
CenUSA Bioenergy Project: What Master Gardeners are learning about biochar, soils, and bioenergy (Part 1)	K. Jeannette, Research Associate, U of MN	Blog post	Jan. 30, 2013
Choosing and Using Biochar for Research in Biochar Test Gardens (Part 2)	K. Jeannette	Blog post	Feb. 8, 2013
Planning, Preparing, and Planting Minnesota Biochar Test Gardens (Part 3)	K. Jeannette	Blog post	Feb. 15, 2013
2012 The University of Minnesota Biochar Test Gardens and Challenges (Part 4)	K. Jeannette	Blog post	Feb. 21, 2013
The First Year's Data from the 2012 CenUSA Biochar Demonstration Garden Report	L. Davenport-Hagen, K. Jeannette	Blog post	Mar. 19, 2013
Biochar as a Soil Amendment	L. Davenport-Hagen	Tabletop display	2013 – 2015
Planting Day at the Fond du Lac Biochar Demonstration Garden	K. Jeannette	Blog post	Jun. 26, 2013
CenUSA Extension Master Gardener Biochar Demonstration Gardens – The Beginning of Year Two	K. Jeannette	Blog post	Jul. 30, 2013
Is Biochar a Good Soil Amendment?	J. Weisenhorn	Poster	University of Minnesota Extension Program Conference, Oct. 2013
Update on Biochar Study	J. Weisenhorn	Webinar	Aug. 13, 2014
CenUSA Annual Meeting Helps Extension Master Gardeners Connect Native Grass, Biochar and Biofuel Research	K. Jeannette	Blog post	Aug. 27, 2013
Research Experience, Wasp Nests, Teamwork and Sprinklers Gone Wild	M. Maynard, University of Minnesota Extension Master Gardener	Blog post	Sep. 16, 2014
2014 CenUSA Bioenergy Project	M. Maynard	Blog post	Dec. 2, 2014
2015 Search for Excellence Awards – Research — 1st Place Winner	M. Maynard	Blog post	Nov. 4, 2015
Researching Biochar	M. Maynard	Blog post	Sep. 30, 2015

Project Details and Methods

Due to the nature of the research question "Is biochar beneficial and suitable as a soil amendment for home gardens?" it was important to approach this study in the same way a home gardener might prepare and plant a vegetable garden.

Biochar demonstration gardens were established at four Minnesota locations:

- SPC – U of MN campus, St. Paul: silt-loam soil, formerly a prairie grass demonstration plot.
- ARB – Minnesota Landscape Arboretum, Chaska: silt-loam soil, formerly a managed lawn area.
- AND – Extension Regional Center, Andover: sandy soil, formerly an unmanaged weedy area.
- FDL – Fond du Lac Tribal Community, Brookston Community Center, Cloquet: sandy soil, formerly a mowed play turf and building site (a buried cement slab was discovered after Yr 1).

The sites were selected because of soil type, public visibility and accessibility, local populations of interested volunteers, volunteer accessibility to facilities, and infrastructure and equipment storage. Each site measured 1000 ft^2 and the crops were replicated into three 300 ft^2 plots:

- Control plot (CTRL), no biochar added to soil.
- Treatment 1 plot (T1), soil amended with ½ lb. biochar/ft^2 (150 lbs. total).
- Treatment 2 plot (T2), soil amended with 1 lb. biochar/ft^2 (300 lbs. total).

Granular biochar sourced from hardwood slash was donated by Royal Oaks Enterprises, LLC, Branson, MO. The biochar was rototilled into T1 and T2 plots at initial garden establishment (Spring 2012). No further biochar was added, nor were the plots rototilled any other time in the four years of the study with the exception one time at AND due to volunteer error. While CenUSA research was primarily focused on perennial switchgrass as biomass, granular biochar from hardwood slash was more readily available in large quantities. In addition, biochar from hardwood slash (black carbon) produced by traditional methods (kilns or soil pits) reportedly possessed the most consistent yield increases when added to soils (Spokas, et. al., 2012).

Baseline soil tests were conducted before adding biochar (Spring 2012); subsequent soil tests were conducted each year at University of Minnesota Soil Testing Laboratory to measure changes in soil pH, organic matter and total organic carbon. Synthetic fertilizers were applied prior to planting each spring per soil test lab recommendations. No additional biochar, organic soil amendments, or pesticides were added during the entire study.

The compilation of the soil reports indicated that biochar treated soils exhibited an increase in percent organic matter. Andover soils demonstrated a rise in pH changing soil pH from acidic to neutral or nearly neutral thus improving growing conditions for crops (Table 2).

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Table 2: Soil test results for Control, T1 and T2 plots, 2012 – 2015
Green: increase from baseline. Orange: decrease from baseline

	Andover Control				Arboretum Control				St. Paul Control			
	BASELINE Spring 2012	Fall 2012	Fall 2013	Fall 2015	BASELINE Spring 2012	Fall 2012	Fall 2013	Fall 2015	BASELINE Spring 2012	Fall 2012	Fall 2013	Fall 2015
Organic matter	2.5	1.8	2.1	2.1	7.4	9.8	9.6	9.4	10.8	8.9	8.8	10.3
pH	5.5	5.5	5.3	5.5	7.5	6.8	6.5	7.1	7.5	7.3	6.9	7.4
Total organic carbon		1.02	1.47	1.20		5.84	4.77	5.31		5.39	4.88	6.12
	Andover T1				**Arboretum T1**				**St. Paul T1**			
	BASELINE Spring 2012	Fall 2012	Fall 2013	Fall 2015	BASELINE Spring 2012	Fall 2012	Fall 2013	Fall 2015	BASELINE Spring 2012	Fall 2012	Fall 2013	Fall 2015
Organic matter	2.5	2.5	2.5	3.0	7.4	11.2	11.1	10.4	10.8	9.7	11.0	12.6
pH	5.5	6.4	6.2	6.5	7.5	7.1	7.1	7.3	7.5	7.3	7.4	7.4
Total organic carbon		2.78	2.58	1.79		7.63	6.81	7.54		6.51	6.42	9.35
	Andover T2				**Arboretum T2**				**St. Paul T2**			
	BASELINE Spring 2012	Fall 2012	Fall 2013	Fall 2015	BASELINE Spring 2012	Fall 2012	Fall 2013	Fall 2015	BASELINE Spring 2012	Fall 2012	Fall 2013	Fall 2015
Organic matter	2.5	1.7	3.1	3.7	7.4	14	10.8	10.9	10.8	10.1	11	11.6
pH	5.5	6.2	5.9	7.1	7.5	7.1	7.1	7.4	7.5	7.4	7.3	7.6
Total organic carbon		1.19	1.67	2.85		7.19	5.95	8.81		6.20	5.77	9.29

Seeds were selected and purchased commercially for crops commonly grown by home gardeners. The EMGs consulted and followed the seed packet instructions for starting seeds/direct seeding, and harvested according to the days-to-maturity (Table 3). According to typical home gardening practices, the sites were planted 3-7 days after the average frost-free date for the USDA hardiness zone. Seven crops were considered successful over the four years. Sites were irrigated per available facilities:

1. SPC - in-ground, commercial system
2. AND – oscillating sprinklers on a manually set timer
3. ARB and FDL – manually by oscillating sprinklers

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Table 3: Crop List Biochar Demonstration Gardens 2012-2015						
Common name	**Scientific name**	**Transplant/ Seed**	**Planting date**	**Days to maturity**	**# Plants/plot**	**Harvest method**
Basil, Italian large leaf	*Ocimum basilicum*	Transplant	Late May – early June	40-65 days	12 plants	Harvested 3 rd wk. of July. Cut at ground level. Total plant weighed.
Blue Lake Bush Beans	*Phaseolus vulgaris 'Blue Lake 276'*	Direct sown; 60/seeds/row; thinned to 15 plants/label	Late May – early June	52 days	15 plants	Beans 6" or longer harvested 4X over a 2-wk period starting the 3rd week of July.
Tasty Green Hybrid Cucumbers	*Cucumis sativus 'Tasty Green Hybrid'*	Transplant	Late May – early June	62 days	9 plants (3/trellis)	4 Harvests of fruits 8" or longer starting Aug. 1 over 2 wks.
Blue Curled Vates kale	*Brassica oleracea* 'Blue Curled Vates'	Transplant	Late May – early June	60 days	7 plants	Cut at ground level and weighed Aug. 1.
King Arthur Hybrid Sweet Bell peppers	*Capsicum annuum* 'King Arthur Hybrid'	Transplant	Late May – early June	62 days	8 plants	Fruits of mature size harvested once/wk. over a 2-wk. period starting July 31.
Potatoes: Kennebec (2012), Runestone Gold (2013, 2014), Yukon Gold (2015)	*Solanaceum vulgaris* varieties 'Kennebec', 'Runestone Gold', 'Yukon Gold'	Direct sown seed potatoes	Late May – early June	90-100 days	5 – 'Kennebec' reduced to 3 in 2013, 2014, 2015	'Kennebec' was selected in 2013. Replaced with a U of MN variety 'Runestone Gold' in 2013, 2014. In 2015 'Runestone Gold' was unavailable and replaced with 'Yukon Gold'.
Celebrity hybrid tomatoes	*Lycopersicon esculentum* 'Celebrity hybrid'	Transplant	Late May – early June	72 days	5 plants	Only ripe fruits were harvested once/wk over a 3-wk period starting the 4th week of August.

Data from AND, SPC and ARB were averaged by site to determine the Average Harvest Weight (AHW) per plant. Calculations compare the CTRL plots with the biochar plots to determine the percentage of change in AHW and the potential benefits to plant yield associated with the biochar treatments (Table 4).

The FDL demonstration garden did not provide sufficient data from 2012-2015 due to initial unforeseen garden site circumstances, and as the project evolved, volunteer involvement with after-school youth programming took precedent. The biochar demonstration took on a new role as the gardening center of the FDL local Junior Master Gardener (JMG) program. Ten to twenty youth, ages 5-14, were engaged in after-school gardening activities that focused on learning about research and the basics of growing and preparing healthy foods. This program was developed and taught by Fond du Lac tribal community EMGs. This approach to the demonstration garden proved more valuable to the local FDL community. According to DePriest and Krasny (2004), students should become actively involved in "learning science as science is practiced," and calls for the involvement of community organizations to enhance students' research experiences.

Table 4: Total percent (%) change in average harvest weight per plant (AHW)

Total percent change (%Δ) in Average Harvest Weight per plant (AHW) 2012-2015 between control (CTRL) and biochar (T1, T2) plots

		Andover					Arboretum					St Paul				
		CTRL	T1		T2		CTRL	T1		T2		CTRL	T1		T2	
	PLOT	(g)	(g)	% Δ	(g)	% Δ	AHW (g)	(g)	% Δ	(g)	% Δ	(g)	(g)	% Δ	(g)	% Δ
Average Harvest Weight in grams (AHW)	BASIL	174	148	-14.9	170.5	-2.2	219.7	264.3	**20.3**	204	-7.2	335	313.9	-6.2	313	-6.3
	BEANS	13.6	24.7	**81.6**	17.2	**26.5**	20.4	30	**47.1**	27.2	**33.3**	28.5	27	-5.3	27.9	-2.1
	CUCUMBERS	451	530	**17.6**	656.5	**45.7**	1651.2	1472	-10.9	1371	-17.0	695	505.6	-27.2	1218	**75.2**
	KALE	272	401	**47.1**	464.9	**70.7**	938.9	1112	**18.5**	970	**30.0**	846	988.2	**16.8**	1096	**29.6**
	GR. PEPPERS	55.7	57	**2.3**	36.6	-34.3	50.8	69.4	**36.6**	59.6	**17.3**	12.9	23.8	**54.2**	64.2	**80.0**
	POTATOES	683	1009	**47.7**	880.8	**28.9**	785.5	924.4	**17.7**	1107	**41.0**	966	1225	**26.8**	1080	**11.8**
	TOMATOES	303	502	**65.9**	596.7	**97.1**	522.3	680.3	**30.3**	601	**15.1**	525	420.9	-19.8	445	-15.3

Biochar Variability

Some scientists acknowledge that plant yield varies widely in biochar research (Spokas, et. al. 2012; Biederman & Harpole, 2012) making it difficult to truly determine the level of benefit. In biochar studies reviewed, half reported an increase in plant yield after adding black carbon or biochar, while 20% of reviewed studies noted decreases in plant yield, and 30% of studies reviewed reported no difference in plant yield from the addition of biochar. These results should be taken as reflective of these studies *only* and not the overall positive effects of biochar (Spokas et. al., 2012). Source of material, pyrolysis conditions, interactions with climate, soil type, and fertilization all contribute to uncertainty in how biochar interacts with organisms (Biederman & Harpole, 2012). Informally, EMG reported they found biochar-amended soils "less compacted" and "easier to plant in"; however, results from a soil compaction test were insignificant (Spokas, 2016). It is important to also consider that while we made every effort to minimize variables by preparing and educating volunteers, there was potential for differences of interpretation and subjectivity that may result in some variability in yield data. These differences may be lessened in future studies by reducing variables such as the number of different crops and having a smaller and consistent pool of individuals.

Impacts on volunteer knowledge and skills

Upon completion of the project, 79 EMGs were asked to complete an outcome evaluation. Forty-three completed usable surveys, a 55% response. Volunteer involvement provided a high level of volunteer motivation and commitment to growing and maintaining plants, as well as collecting data on productivity. EMGs also reported increased personal knowledge about biochar and scientific research, and that they felt their observation skills improved through their experience. Extension professionals find value in EMG involvement in research as “citizen scientists” (Relf, et al., 1990). “Citizen Science” engages the public in collecting data to be analyzed and interpreted by professional scientists (Meyer et al., 2014). EMGs have also shown to be motivated by positive personal experiences gained through volunteerism such as self-improvement, increased knowledge and helping others (Rohs, Stribling, & Westerfield, 2002).

In 2015, EMGs received national recognition by their peers and received the *Search for Excellence Award* in research at the International Master Gardener Conference, Council Bluffs, Iowa. This project was also awarded the 2016 Minnesota state award for Search for Excellence in Consumer or Commercial Horticulture by the National Association of County Agricultural Agents (NACAA).

Conclusion

There were many variable conditions between the sites: soil type, irrigation methods, weather and micro-climates. However, many notable observable differences indicate that biochar has potential benefits for some soil types and crops.

Notable observations include:

- Organic matter increased in all soils.
- Soil tilth improved in all soils.
- Biochar appeared to increase AHW of kale, green pepper and potato in sand and silt-loam soils.
- The pH of biochar-amended soils at the Andover site increased from acidic (5.5) to nearly neutral (6.5) to slightly over neutral (7.1)
- Sandy, acidic soils low in organic matter may be improved for some vegetable production by adding biochar.
- Biochar appeared to decrease AHW of basil.
- Biochar appeared to decrease AHW of cucumbers in silt-loam soils.
- The SPC site exhibited a decrease in AHW in T1 and T2 plots of basil, beans, and tomatoes.

Observations and data recordings made by EMG volunteers were subject to individual interpretation about the instructions that sometimes resulted in errors. More training and oversight may have improved results; however, adult volunteers value autonomy. Weather also played a role in inconclusive results. Because of these variabilities, there is not enough consistency in the data to determine if there are scientifically measurable benefits of biochar as a soil amendment for the typical home garden. Future studies of this nature would be improved by growing fewer crop varieties under more controlled conditions. While we had over 50% retention of EMGs, who contributed significant volunteer hours throughout the four-year study, retaining a smaller volunteer group 100% committed for the full four-year study would have reduced training and improved consistency.

Literature Cited

Biederman, L.A. & S.W. Harpole. 2013. Biochar and its effects on plant productivity and nutrient cycling: a meta-analysis. GCB Bioenergy 5:202-214. http://onlinelibrary.wiley.com/doi/10.1111/gcbb.12037/abstract (Open Access)

DePriest, T. & M Krasny. 2004. Engaging County Educators in Science Education Reform: The New York 4-H Environmental Inquiry Program. J. Extension. 42(2) Article 2RIB4. https://joe.org/joe/2004april/rb4.php (Open Access)

Frendo, M. 2013. Self-Determination Theory: A Framework for Understanding Volunteer Motivation and Retention. The International Journal of Volunteer Administration. Volume XXIX, No. 3: 6.

Glen, C., G. Moore, K.S.U. Jayaratne & Lucy Bradley. 2013. Characteristics of Extension Demonstration Gardens. J. Extension. 51(2) Article 2RIB8. https://joe.org/joe/2013april/rb8.php (Open Access)

Meyer, N., S. Scott, A.L. Strauss, P.L. Nippolt & Oberhauser, K.S. 2014. Citizen science as a REAL environment for authentic scientific inquiry. J. Extension 52 (4) Article 4IAW3. https://joe.org/joe/2014august/iw3.php (Open Access)

Mukherjee, A. & R. Lal. 2014. The Biochar Dilemma. Soil Research 52:217-230. http://dx.doi.org/10.1071/SR13359

Rohs, F. R., J.H. Stribling & R.R. Westerfield. 2002. What personally attracts volunteers to the Master Gardener program? J. Extension. 40(4) Article 4RIB5. http://www.joe.org/joe/2002august/rb5.php (Open Access)

Relf, P., J. Williams & E. Silva. 1990. Master Gardener Volunteers on the Virginia Tech Campus. HortScience 25(1):706

Spokas, K. A., K. B. Cantrell, J. M. Novak, D. W. Archer, J. A. Ippolito, H. P. Collins, A. A. Boateng, I. M. Lima, M. C. Lamb, A. J. McAloon, R. D. Lentz & K. A. Nichols. 2012. Biochar: A Synthesis of Its Agronomic Impact beyond Carbon Sequestration. J. Environ. Qual. 41:973-989. doi:10.2134/jeq2011.0069. Abstract: http://www.biochar-international.org/node/3470

Correspondence, interview with Spokas, 2016

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"Our vision is to create a regional system for producing advanced transportation fuels derived from perennial grasses grown on land that is either unsuitable or marginal for row crop production. In addition to producing advanced biofuels, the proposed system will improve the sustainability of existing cropping systems by reducing agricultural runoff of nutrients and soil and increasing carbon sequestration."

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