ENHANCING URBAN FOOD PRODUCTION, ECOSYSTEM SERVICES, AND

LEARNING IN COMMUNITY GARDENS THROUGH COVER CROPPING AND

PARTICIPATORY ACTION RESEARCH

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ENHANCING URBAN FOOD PRODUCTION, ECOSYSTEM SERVICES, AND LEARNING IN COMMUNITY GARDENS THROUGH COVER CROPPING AND PARTICIPATORY ACTION RESEARCH

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Urban community gardeners make important contributions to healthy food access and environmental stewardship. I conducted gardener interviews and ecological sampling to describe agroecological and social characteristics of 61 food-producing gardens in New York City. Gardeners devoted the greatest proportion of garden area to food production and supplied substantial shares of their households' produce needs. Challenges for sustainable crop production included: poor soil quality in raised beds due to sandy textures and low water-holding capacities, excessive soil nutrient contents, insect pest damage, and weed pressure.

To identify promising cover crops for enhancing ecosystem services, I conducted field experiments in 17 Brooklyn, NY gardens over two field seasons. Compared to winter-kill cover crops, over-wintering cover crops had greater biomass, weed suppression, legume % N from fixation, and N fixed. Rye and rye/legume bicultures were most productive (average biomasses > 10,000 kg/ha). On average, hairy vetch and crimson clover monocultures and rye/vetch mixtures fixed 190 kg N/ha or more, enough to supply vegetable crop needs. Rye/vetch mixtures showed complementary and facilitative interactions, while rye/crimson clover and oat/pea mixtures had low legume biomass and total N fixed. Surprisingly, compared to vetch

monocultures, rye/vetch mixtures had greater legume soil N uptake (possibly due to priming of SOM decomposition by rye root exudates) and lower % N from fixation.

Finally, I conducted a case study of the participatory action research (PAR) project described above to address the question: How can PAR be designed to achieve positive outcomes for science, education, and communities? Collaborative research design and interpretation tapped gardeners' local knowledge to improve our practices. Engaging gardeners in cover crop monitoring strengthened their ecological knowledge and adaptive management skills. Facilitating opportunities for participants to share their knowledge (e.g., field days) supported leadership development. Sustained, in-person support enabled gardeners to implement cover cropping practices with agricultural and environmental benefits. Key challenges included: addressing community-defined goals within the constraints of a dissertation project and providing sufficient one-on-one guidance with limited funding for community-based partners. Despite its challenges, PAR in urban gardening contexts may develop knowledge and skills that support improved stewardship practices and community capacities.

BIOGRAPHICAL SKETCH

Megan was born and raised in the suburbs of northern Illinois, where she developed a passion for the outdoors in the company of her loving parents, Fred and Liz Gregory, energetic sister Kelly, cherished dog Rusty, friends, and teachers. Nurtured by a truly outstanding high school biology teacher, Roy Triveline, Megan's love for nature deepened and grew into a fascination with ecology and a commitment to caring for the Earth in her personal and professional life. At the same time, her social conscience was stirred by the mentorship -- and even moreso by the example – of the faith community called Wildwood Presbyterian Church, which gathered in a barn donated to the congregation and renovated in the '60s (meaning that indeed, Megan WAS raised in a barn). Guided by the Revs. Greg and Kathy Bostrom and other dedicated members of her church family (God bless middle and high school youth group advisers!), Megan began a life-long journey of seeking relationship and solidarity with people struggling to secure what she had enjoyed from birth – the material basics of life, opportunity, dignity, and voice in the decisions that shape their communities. To her early guides on this journey, as well as the diverse communities who welcomed her so warmly into the work of repairing homes and lives together, she is deeply grateful.

As Megan began her undergraduate work in Biology and Environmental Studies at St. Olaf College in Northfield, MN (Um Yah Yah!), she developed a keen interest in sustainable agriculture as a point of intersection between her passions for environmental stewardship and social justice. With the guidance of Professors Kathy Shea and Gene Bakko, she partnered with local farmers to study the effects of different crop rotations and tillage practices on soil and water quality and energy use on farms. Farmer Dave Legvold took a special interest in this work and its implications for stewardship of precious soil and water resources. He accompanied Megan in

the field to see what critters thrived (and did not thrive) in soils under different management, invited her and her roommate to ride along on the tractor during the fall grain harvest, and connected Megan with the Canon River Watershed Partnership to prepare materials for their farmer education programs based on her research. While she was a student at St. Olaf, Megan also spent two January terms in Ecuador working with rural development organizations in organic agriculture and reforestation. Taken together, her experiences in the U.S. and abroad sparked Megan's interest in conducting participatory research with farmers to develop and share sustainable agricultural practices. In addition to (but inseparable from) St. Olaf's contribution to her growth as an agricultural scientist/educator, this community of faith and learning nourished Megan with a broad liberal arts curriculum that included sociology and theology alongside field ecology and organic chemistry; a vibrant faith community that wove worship, study, and service into the fabric of daily life; and constant reflection on meaning and purpose in the company of thoughtful fellow students, professors, and community members who were each, in their own ways, seeking to build a more just and sustainable world.

From 2004 – 2008, Megan served as an Agroforestry and Environmental Education Volunteer in Peace Corps / El Salvador, where she lived and worked with a rural community in agroforestry and soil conservation, organic vegetable gardening, water and sanitation, and environmental education projects. (She also got pretty good at chasing and catching chickens, though she was never a match for her younger Salvadoran brothers!) She remains in touch with her host 'parents' Lidia and Melvin and feels the pull of bonds of friendship and family forged in that village. Megan's time in El Salvador also strengthened her commitment to seeking climate justice as she witnessed, firsthand, the impacts of climate change on people and a place she grew to love. Watching smallholder farm families lose precious harvests to erratic weather patterns

continues to focus her political energy on mitigating what she sees as the most far-reaching environmental injustice of our time -- as well as an opportunity to create a more resilient global society that honors and provides for the needs of current and future generations.

Motivated by a desire to contribute to farming and food systems that nourish people and the land, Megan then entered a graduate program in Horticulture at Cornell University, adding minors in Adult and Extension Education and Natural Resources along the way. As recounted in this dissertation, she had the great privilege of working with community gardeners in New York City to develop and share ecologically-based gardening practices that enhance vegetable production and environmental sustainability. Inspired, guided, and challenged by many brilliant faculty mentors and fellow students, she explored research interests in cover cropping and sustainable soil and nutrient management, using a Participatory Action Research approach to engage gardeners in discovering and fostering beneficial ecological processes in their gardens.

While at Cornell, Megan was also fortunate to connect with several of Ithaca's many wonderful and civically active people and organizations. As a member of First Presbyterian Church (FPC) of Ithaca and its Committee on Justice, Peace, and the Integrity of Creation, she co-organized an interfaith study/action series on climate justice, which grew into what is now the Interfaith Climate Action Network. Megan was also involved in the early stages of Gardens 4 Humanity, a community gardening and food justice organization patiently built by Jemila Sequeira of Tompkins County Cooperative Extension in partnership with local residents. During her time in Ithaca, Megan also tried (in vain) to keep the woodchucks away from her butternut squash at the Ithaca Community Gardens, shared meals and conversation and voter registration drives with people from all walks of life as an Advocacy Volunteer at Loaves and Fishes, and explored the beautiful gorges (of 'Ithaca is Gorges' t-shirt fame) with FPC's young adult

fellowship group. Thanks to each of these people and experiences (and many others!), she learned and grew in new ways that complemented her more formal graduate school endeavors.

In August of 2015, with both field and lab work complete but the dissertation not yet finished, Megan moved to Winston-Salem, North Carolina to begin work as Community Gardening Coordinator with Forsyth County Cooperative Extension. In this new role, she has the great joy of working with neighborhood groups to create and sustain community gardens throughout the county. Blending her passions for community education and organizing, horticulture, and environmental stewardship, it is truly a 'dream job' (except for needing at least ten more staff to properly support the growing community gardening movement!). Despite vowing not to get involved with any 'community activities' until her dissertation was done, Megan has somehow already found herself working with the newly-formed Environmental Justice team at Trinity Presbyterian Church and participating in the Presbyterian Inter-Racial Dialogue in Winston-Salem.

After finishing this dissertation and her graduate program at Cornell, Megan looks forward to reconnecting with family (and especially to teaching her niece Juniper to play in the dirt!), setting down roots in her new home, drawing on all she has learned to support Forsyth County's passionate community gardeners, and of course, taking full advantage of North Carolina's amazing growing season.

GRATITUDES

Where to begin? As wise people have acknowledged for thousands of years, learning,

growth, and work of enduring value occur in community. I have received inspiration, guidance,

support, mentoring, collaboration, and friendship from so many people in so many aspects of

life. While I will not be able to name them all or properly celebrate their gifts here, I will do my

best – and then try to live out as much of what they have taught me as I can. This is, I believe,

the most appropriate response to their generosity. I'll begin with those who contributed directly

to the work described in this dissertation -- of understanding and enhancing community

gardeners' work growing food, greening neighborhoods, and cultivating knowledgeable and

connected citizens – and move gradually outward to embrace the many people and communities

who have shaped who I am, both through kindness shown to me and their examples leading lives

of integrity.

First, I am deeply grateful to the dedicated community gardeners who welcomed me into

their gardens and participated in the various inquiries reported in the pages that follow. New

York City is no doubt a better place thanks to your tireless efforts to bring neighbors together

and create beauty and abundance out of harshness and scarcity. I am humbled and honored if

this work has, in some small way, supported your hopes and dreams for your neighborhoods.

Thank you for sharing your time, insights, friendship, and – for those who planted cover crop

research plots – your garden space. I realize that the latter is a scarce and precious thing in New

York City, and I appreciate your willingness to share some of it with me for a time!

Special thanks goes to the gardeners of the Brooklyn Farmer Field School (FFS), who

patiently helped me understand the joys and challenges of gardening in Brooklyn, select cover

crops to test, and plant and monitor cover crops over more than two years. Gardeners who

gardening in NYC in the early stages of this project and introduced me to many gardens and gardeners. I am grateful to them for trusting me, believing that my work might contribute something of value to the community gardening movement in NYC, and welcoming me into the families of gardeners they serve with such dedication.

As I developed closer relationships with gardeners and began the participatory research and education effort on cover cropping described in Chapters 2 and 3, I was supported by local garden educator partners who continued to connect me with gardeners, assisted with research design and educational workshops, and contributed cover crop seed and row cover. In East New York, Deborah Greig, David Vigil, Sarita Daftary, Daryl Marshall, and the entire staff of the amazing East New York Farms! project provided valuable input and tremendous support. Lorraine Brooks and Gretchen Ferenz of Cornell University Cooperative Extension – NYC and Hannah Riesley-White of Green Guerillas provided similar support in Bedford-Stuyvesant. I would have been unable to do this work without the help of community educator partners: Nayda Maymi and Brenda Thompson-Duchene in East New York, and Linda Casey and Deborah Batiste in Bedford-Stuyvesant. In addition to participating as gardeners, they assisted with workshop scheduling and reminders, curriculum development, and facilitating planting and monitoring workshops in each garden. They truly championed this project and kept me grounded in the needs and opportunities of Brooklyn gardens and gardeners; for this and for their friendship, I am grateful.

A number of fellow students, professors, and community-based partners also provided valuable input that shaped and enabled this research. At Cornell, I was fortunate to be a part of two vibrant lab groups, Laurie's Agroecology Lab and Marianne's Civic Ecology Lab (does this make me a Civic Agroecologist?). These bright and inquisitive groups of scholars created an

ornamental and weedy plants in the gardens as we compiled species inventories. Thanks to Tom Whitlow of Cornell Horticulture for introducing me to hemispheric photography techniques for quantifying light availability, and for generously (and bravely) lending me his equipment to take the necessary photos in NYC gardens. Julie Grossman, then at North Carolina State University and now at the University of Minnesota, provided input on initial versions of the cover crop monitoring checklist. Her suggestion to observe the inner color of legume nodules (as an indicator of nitrogen fixation) proved quite a hit with gardeners, as recounted in Chapter 3.

Many thanks to hard-working field assistants Sonali Bhasin, Abigail Cohen, Erin Eck, Johanna Katz, Rob Meyer, Alicia Miggins, Margaret Pickoff, and Bonnie Schiffman. They were a tremendous help (and great company) as we mapped gardens, inventoried plant species, counted whiteflies on collards and parasitic wasps on sticky cards (among other insects), sampled soil, and planted, monitored, and sampled cover crops. In the lab, Heather Scott and Carri Marschner provided skilled instruction in analyzing soil and plant samples and substantial (and cheerful!) assistance with sample processing, as well as keeping the ailing and finicky LECO CN analyzer limping along. Melissa Harbut, Ross Hathaway, Brooke Pian, Bonnie Schiffman, and Sarah Zipfel also put in many hours assisting with soil and plant sample analysis.

Tom Archibald, John Armstrong, Jesse Delia, Christine Moskell, Christine Porter, Tim Schaffer, Jennifer Shirk, and Philip Silva all offered helpful perspectives on participatory research, community education, and/or learning in urban gardening and environmental stewardship contexts as I planned the research presented in Chapter 3 and presented my initial interpretations. They also inspired and challenged me with their own work as engaged scholars and dedication to the well-being of people, communities, and ecosystems, each in their own ways and contexts. I am so grateful to have travelled a stretch of our journeys together, and hope

that we can remain friends and colleagues. Please keep on being the wonderful people that you are, and doing the important things that you do. The world needs the thoughtful, ethically grounded 'public work' that you all pursue so passionately and well.

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In addition to the people who contributed directly to shaping and realizing the work described in this dissertation, I have enjoyed the inspiration, support, and friendship of many others during my time at Cornell. In many ways, their contributions to this work are as essential as those recounted above. In this group, my first thanks goes to my family. My mother, Liz, and father, Fred, raised me and my sister to believe that all opportunities were open to us – and have supported us in pursuing those opportunities and, we hope, leaving the world a bit better than we found it in the process. My sister Kelly visited me for my 30th birthday during my field work Brooklyn, so she shares a special appreciation for the gardens and gardeners I came to love. Along with my parents, Kelly and her husband, Patrick Hawks, have cheered me on. I look forward to spending more time together in my post-dissertation life, and especially to being an aunt to Kelly and Patrick's beautiful daughter, my niece Juniper.

In addition to my graduate studies, my life in Ithaca was rich and full with meaningful relationships in the broader community. I am immeasurably grateful to the community of faith called First Presbyterian Church (FPC) of Ithaca and to the pastoral leadership we were blessed to have for various stretches of my time in Ithaca: Rev. James Henery, Rev. Kristin Sundt, Rev. Alice Rose Tewell, and Rev. Kirianne Weaver Riehl. As individuals and as a congregation you helped me to live (most of the time) as a person of hope, and offered the best companionship that anyone could ask for in our shared journey of being the church in the world. In your midst, I found opportunities for thoughtful and challenging reflection on Scripture, committed action in

service and solidarity with God's children and God's creation, and a genuinely caring and supportive community that shares joys and sorrows. You kept me grounded (again, most of the time) in the ultimate reasons that I undertook graduate study and the work described in this dissertation: To "serve and keep" the garden of Earth that has been entrusted to us (Genesis 2:15). To ensure that all enjoy the nourishment, health, dignity, and freedom that they need to realize their full potential as members of the Beloved Community, each contributing to "repair[ing] the ruined cities" and building up our common life (Isaiah 58:6-12, 61:1-4). To live into a calling to seek wholeness and communion for people and the Earth, for human and ecological communities, together. It is so easy to forget all of this amid the pressures and competing institutional priorities that come with being a graduate student at an intensely competitive research university. To the extent that I have managed to remain committed to my true calling, it is because of your example, support, and companionship. To the extent that I have failed – and in many places and ways, I have -- I take full responsibility.

Several groups connected to FPC deserve special mention. The Committee on Justice, Peace, and the Integrity of Creation (JPIC) have been my soulmates almost from the day I set foot in FPC. Thanks to Elmer Ewing, the late Bob Finn, Sandra Greene, Sabrina Johnston, Chantal Koechli, Brad McFall, Susan Multer, Angela Possinger, Rev. Kristin Sundt, Rev. Alice Rose Tewell, and John Weiss for their friendship, their passions and commitments to realizing a more just and whole world, and for supporting the various ideas I brought to the table in spirit and in action.

The seed of an idea for what became the Interfaith Climate Action Network (ICAN) was first tended and watered by JPIC, but quickly gained the support, creativity, and commitment of a broad group of people of faith and conscience in Tompkins County from diverse traditions. I

am so grateful for the planning team that created and led the 2014 Interfaith Climate Justice "Inquiry to Action" series, which grew into the vibrant and active network known today as ICAN: Elmer Ewing, Aileen Fitzke, Laurie Konwinski, Rev. Taryn Mattice, Margaret McCasland, Brad McFall, Louise Mudrak, Jimmy O'Dea, and Todd Saddler, along with many others who agreed to speak about their efforts to mitigate climate change and share resources for others seeking to do so in their congregations and communities. All of this took place during what was for me a very intense period of lab work processing soil and plant samples. It is telling that some days I arrived at lab by 5:30 am, worked until 6:30 pm, walked down to FPC exhausted for a 7:00 pm planning meeting… and left after 9:00 pm more energized and hopeful than when I came, thanks to all of you. I am so, so honored to have played a small part in planting and tending the seed that grew into ICAN, and I can't wait to see all you will do. You give me so much hope for the world. I'm still on your email list, both to keep in touch with dear friends, and so I can steal all your cool ideas and put them to work here in North Carolina. I trust you won't mind. We're working toward the same goal, after all.

The Young Adult Fellowship group at FPC has been a constant source of friendship, support, and grounding since it was started by the Rev. Alice Rose Tewell. I am lucky to have shared book discussions (and life discussions) and many hikes in the beautiful Finger Lakes region with Micah Beck, David Flannelly, Hayeon Kim, Chantal Koechli, Julie Niewiadomski, Angela Possinger, Adam Tewell, Rev. Alice Rose Tewell, and John Yao. Thank you all. You're the best.

From my time in Ithaca, I am also grateful for the friendship and good work of the folks of Gardens 4 Humanity, especially Jemila Sequeira; the Ithaca Community Gardens, especially its dedicated leadership in Judith Barker, Doug Dylla, Ron Liso, Sheryl Swink, and others; and

the remarkable boundary-eschewing community that is Loaves and Fishes of Tompkins County, especially Director Christina Culver, Advocacy Coordinator J.R. Claiborne, and all my fellow volunteer advocates. In your company around your tables, I enjoyed authentic fellowship with people from all walks of life – people of every age, vocation, economic and educational background, and political persuasion; people who had experienced every hardship and yet possessed a wide range of gifts, talents, and insights that are not sufficiently recognized and celebrated in the 'mainstream' of our society. A special thanks is due to the incomparable Neil Oolie for his big heart, mentorship of all the volunteer advocates, walks back up the hill after dinner (accompanied by excellent conversations about politics and life), and his cheerful admonition each time we parted ways to "be bad and cause trouble!" I've done my best.

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Also deserving of my thanks and appreciation are the people who cultivated my early passions for ecology, agriculture, and community, without whom I would not be who I am, nor do the work that I do, today. My high school biology teacher and friend, Roy Triveline, not only taught me and countless other teenagers to understand living things and the Earth that sustains us, he also instilled in us a sense of wonder, appreciation, and responsibility to live as harmoniously as possible in community with all our fellow-inhabitants of the planet we call home. I have tried to carry that spirit with me.

At St. Olaf College in Northfield, MN, many brilliant and caring faculty in diverse fields nurtured not only my mind, but also my heart and my praxis of reflective, collective action in pursuit of a more just and sustainable world. I would especially like to recognize Kathy Shea and Gene Bakko, who encouraged and advised my first foray into agroecological research, and our farmer collaborator Dave Legvold, who enthusiastically accompanied us on the journey (and

told all his friends in farming, Cooperative Extension, and watershed conservation about it). I'd especially like to thank this trio for pushing me to share our work on soil and water conservation – and its implications for farming practice and policy -- with farmers, the Canon River Watershed Partnership, and other decision-makers. It was tremendously exciting and rewarding to see that our work could inspire and inform efforts toward more sustainable agriculture. To them and the many, many others who make up the community of faith and learning that is St. Olaf College, I would like to say, "Um Yah Yah!", and thanks.

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Since I moved to North Carolina and began work with Forsyth County Cooperative Extension in 2015, I have also been blessed with colleagues and friends who welcomed me into the Extension family and the vibrant network of community gardeners and organizers seeking to build a just, sustainable, and resilient food system that provides for everyone. In addition to providing me with a warm welcome and meaningful work together, they also offered constant encouragement and support in completing the work described in this dissertation (not to mention Swiss chard, kale, turnips, beans, and eggplants to fuel my thinking and writing!). While I cannot name them all here, there are several people I would like to recognize.

County Extension Director Mark Tucker, with great patience and understanding, worked with me to find solutions that balanced my responsibilities to the Forsyth Community Gardening program with my desire to complete the work I began with gardeners in New York. He consistently inquired about my progress and urged me to take the time I needed to finish this dissertation. Although I ignored his advice for almost a year, I sincerely appreciated his concern and I am grateful for the time he willingly granted once I (finally) realized the need for a more concentrated effort to complete this work. My other colleagues in the Forsyth Cooperative

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guidance and service in the various gardens surrounding the church. I promise to help out more next year when I'm not writing a dissertation (thanks be to God!).

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I should also thank writer and activist Parker Palmer, not only for his visionary and world-changing work of helping people of faith and conscience join 'soul and role,' but also for the idea of titling this section 'Gratitudes,' rather than the more conventional 'Acknowledgements,' as he did in *A Hidden Wholeness* (Jossey-Bass: San Francisco, CA, 2004). 'Gratitudes' is a much better expression of the admiration and affection I feel for the people named above.

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Gardener-Researchers in the Brooklyn Farmer Field School

Abib Newborn Garden
Jeanette Carter
Luell Smith

Backyard Gardens
Dora Hinds
Nayda Maymi
Virgina McClaim

Cleveland St. Vegetable Garden
Kele Nkhereanye
Thelma Sampson

Festival Garden
Filiberto Ayala

First Temple of David
Ruben Acevedo
Beverly Edwards
Wayne Fleshman

Hands & Heart Community Garden
George Howell
Justin Myers
Annie Wyche
Kim Wyche

Hart to Hart Community Garden
Stephane Barile
Deborah Batiste
Linda Casey
Margot Dorn
Isabel Fiumano
Esme Hoffman
Barbara Lester
Dorothy Maddix
Maritza Padilla

John the Baptist Community Garden
Yolanda Golden
James Jones
Desiree Montanez

Nehemiah 10 Community Garden
Brenda Forde
Denworth Frederick
Teresa Girard-Isaac
Compton Griffin
Glenda Nicols
Ana Rosado
Lisa Steeple
Veronica Veira
Carol Wharton

Phoenix Community Garden
Marcia Denson
Mark Leger
Bernadette Mitchell
Kelly Simond
Joe Petty
Nathaniel Ridgard

Powell St. Garden
Carmelia Goffe
Brenda Thompson-Duchene

St. John Cantius Garden
Gemma Garcia
Shakema Miller
Pauline Watson

Union St. Garden & Community Development
Gloria Briggs
Chris Carr
Minnie Horton
Lee Horton
Barbara Davis
Bertha Pontoon

United Community Centers Youth Farm
Deborah Greig
David Vigil
UCC Youth Interns

Vernon/Throop Ave.
Yvonne Bennett
Ruth Phillips

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CHAPTER 3

LIST OF ABBREVIATIONS

% H_2O	Soil water content at field capacity (g water / g moist soil)
% NDFA	% Nitrogen derived from the atmosphere (i.e., percentage of legume nitrogen derived from fixation as opposed to soil N uptake)
% Trans Total	Total % transmitted light (diffuse + direct) reaching a given garden plot, as calculated from hemispheric photos and latitude and longitude
B	$\delta^{15}N$ of a legume plant when it derives all N from fixation
BIOS	Biologically Integrated Orchard Systems. See Chapter 3 references: Pence and Grieshop, 2001; Warner, 2007.
C	Carbon
Ca	Calcium
CEC	Cation exchange capacity
CUCE-NYC	Cornell University Cooperative Extension – New York City
CV	Coefficient of variation
$\delta^{15}N$	Deviation of the ^{15}N:^{14}N ratio of a plant sampled compared to atmospheric N in per mil units
ENYF!	East New York Farms! (an urban agriculture and food justice project of United Community Centers in Brooklyn, NY)
FFS	Farmer Field School
fPOM	Free particulate organic matter (not associated with soil aggregates)
K	Potassium
LDI	Leaf damage index (rating of the intensity of visual damage from spider mite feeding on a tomato leaf). See Chapter 1 references: Nihoul et al., 1991; Castiglioni et al., 2003.
Leg	Legume
LER	Land Equivalent Ratio (relative amount of land that would need to be planted in monocutlures to produce equivalent yields to those achieved in a mixture). See Chapter 2 reference: Wiley and Osiru, 1972.

Mg	Magnesium
N	Nitrogen
NYC	New York City
oPOM	Occluded particulate organic matter (inside soil aggregates)
OW	Over-wintering (refers to cover crops that are planted in fall, survive the winter, and mature the following spring)
P	Phosphorous
PAR	Participatory Action Research
PC	Principal Component (an independent, composite variable generated from PCA and representing a major source of variability in a multivariate dataset)
PCA	Principal Components Analysis
pLER	Partial Land Equivalent Ratio (productivity of a plant species in a species mixture divided by its productivity in monoculture)
POM	Particulate organic matter (organic matter > 53 μm in diameter, usually derived from recent inputs)
SOM	Soil organic matter
WK	Winter-kill (refers to cover crops that are planted in late summer, mature in late fall, and die with the first hard freezes of winter)

CHAPTER 1

AGROECOLOGICAL AND SOCIAL CHARACTERISTICS OF NEW YORK CITY

COMMUNITY GARDENS: CONTRIBUTIONS TO URBAN FOOD SECURITY,

ECOSYSTEM SERVICES, AND ENVIRONMENTAL EDUCATION

Megan M. Gregory • Timothy W. Leslie • Laurie E. Drinkwater

Abstract

There is growing public interest and participation in food-producing urban community gardens in North America, yet little research has examined agricultural production and ecological processes in these spaces. We describe the agroecological and social characteristics of 61 food-producing gardens in New York City, drawing on gardener interviews, land-use maps, plant species inventories, arthropod scouting, and soil sampling and analysis. Gardens contained agricultural crops, food production infrastructure, ornamental plants, and recreational areas in varying proportions, indicating that gardens serve multiple and distinct purposes depending on community needs and interests. On average, gardeners devoted the greatest proportion of garden area (44%) to food production, and supplied a large share of their households' produce needs from their community gardens. Solanaceae, Brassicaceae, and Cucurbitaceae crops dominated food crop areas, hindering effective crop rotation to prevent disease and pest problems. Most gardeners grew crops in raised beds constructed with clean fill and compost. These soils

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generally had sandy textures, low water-holding capacity, high organic matter levels (with a large proportion from recent inputs) and excessive nutrient levels. Soil water content at field capacity increased exponentially with total soil carbon, suggesting that organic matter enhances water-holding capacity. Insect pest densities greatly exceeded action thresholds in nearly all gardens for aphids and whiteflies on Brassica crops, aphids on Cucurbit crops, and two-spotted spider mites on tomatoes. Predator and parasitoid densities were generally low (less than one per plant on average), perhaps partially due to low floral and woody perennial cover in most gardens (12% and 9% on average, respectively). Dominant groups of natural enemies were minute pirate bugs, spiders, and parasitoid wasps. A wide variety of people of differing experience levels, incomes, and ethnicities participate in community gardening in NYC, and most gardens host multiple languages. Promising directions for urban gardening research, education, and practice include: 1) Cover cropping to improve soil quality and nutrient management, and diversify crop rotations; 2) Improving access to soil testing and guidance on appropriate use of soil amendments, 3) Enhancing habitat for arthropod natural enemies that provide biological control of insect pests with floral and woody perennial plantings; and 4) Incorporating ecological knowledge and inquiry-based approaches into gardening workshops, educational materials, and technical support, and offering these resources in multiple languages.

Keywords

Introduction

City dwellers, civil-society organizations, and policymakers show growing interest in food-producing community gardens for their potential to improve nutrition and public health, enhance urban environmental quality, and provide opportunities for urban residents to experience the natural world (Alaimo et al., 2008; Krasny and Tidball, 2009; U.S. House of Representatives, 2010; Drake and Lawson 2015). Community gardens are public spaces managed by member-volunteers who grow food crops and/or flowers, shrubs, and trees in individual plots and communal growing spaces (Cohen et al., 2012). Where they host vegetable and fruit production, community gardens may foster food access and healthy eating, in addition to physical and mental health, environmental stewardship, and community organizing (Blair et al., 1991; Armstrong, 2000; Draper and Freedman, 2010; Litt et al., 2011). Supporting and expanding community gardens could benefit many urban dwellers in neighborhoods where people lack access to affordable healthy foods and opportunities for interactions with nature (Miller, 2005; Larson et al., 2009).

Since the late 1800's, food production in community gardens has been a prominent part of urban life in the United States, particularly during times of social and economic change (Lawson, 2005). In New York City (NYC), the contemporary community gardening movement began in the 1970's. In the wake of urban decline and housing abandonment, residents transformed vacant lots into gardens that integrated community development, green space, and local food production (Schmelzkopf, 2002; Saldivar-Tanaka and Krasny, 2004). During this time, a robust network of city-sponsored programs and nonprofit gardening support and advocacy organizations took shape in response to the groundswell of grassroots community gardening efforts (Cohen et al., 2012).

In recent years, these networks have grown as participation in food-producing community gardens increased once again throughout the United States and Canada. Almost 90% of 445 surveyed community gardening support organizations in North America established new gardens from 2007-2011, and existing gardens increased their size and membership (Lawson and Drake, 2012). Seed companies reported increased vegetable seed sales in 2009 (Horowitz, 2009), reflecting renewed interest in food gardening in general. The economic recession of 2008-2009 and increased food prices likely stimulated interest in gardening as people sought to save money on produce (Horowitz, 2009; Draper and Freedman, 2010). However, public interest in gardening may also reflect enduring social movements for sustainable food systems, food justice, and civic environmentalism (Wekerle, 2004; Levkoe, 2006; Svendsen and Campbell, 2008; Teig et al., 2009).

Urban gardens: Social benefits and challenges

Urban dwellers engage in community gardening for multiple reasons. Many gardeners participate partly to grow healthy, fresh, affordable produce (Armstrong, 2000; Draper and Freedman, 2010). Gardeners also value the opportunity to cultivate organically grown and culturally significant vegetables, which may be too expensive or unavailable in low-income neighborhoods (Armstrong, 2000; Baker, 2004; Wakefield et al., 2007; Carney et al., 2012). Access to garden produce may facilitate improved nutrition through increased vegetable consumption (Blair et al., 1991; Alaimo et al., 2008; Litt et al., 2011; Carney et al., 2012). However, food access is rarely the sole motivation for community garden participation. Gardeners also seek to improve health and wellness, practice environmental stewardship, build relationships with neighbors, and organize around other neighborhood issues and needs (Blair et

al., 1991; Armstrong, 2000; Saldivar-Tanaka and Krasny 2004; Ohmer et al., 2009; Draper and Freedman, 2010; Gittleman et al., 2011; Drake and Lawson, 2015).

Challenges associated with urban community gardening stem from access to various types of resources, including material resources (e.g., land, soil) and non-material resources (e.g., human resources, technical assistance). Underlying many of these resource needs are insufficient sociopolitical resources -- access to and influence with policymakers, government agencies and other funders -- particularly for communities of color and low-income neighborhoods (Cohen and Reynolds, 2015).

Among material resource needs, access to land and land tenure are widespread concerns, as most garden spaces are not owned by gardeners and are subject to residential and commercial development (MacNair, 2002; Saldivar-Tanaka and Krasny, 2004; Wakefield et al., 2007; Teig et al., 2009; Guitart et al., 2012). In many cases, uncertainty about continued access to land limits crop selection and discourages investment in infrastructure and perennial plantings (Wakefield et al., 2007; Pfeiffer et al., 2014). Community gardeners also express difficulty obtaining materials (particularly clean soil) and financial resources to garden successfully (Saldivar-Tanaka and Krasny, 2004; Wakefield et al., 2007; Drake and Lawson, 2015).

Even with land and materials, successful community gardens require human and educational resources, including staff and volunteer commitment, labor, experience, knowledge and skills. In general, community gardens rely on volunteers to maintain common areas, fundraise, procure materials, and advocate for land access – all in addition to cultivating plots of vegetables and flowers. Getting new people involved and sustaining participation in common labors are frequent concerns for most garden leaders (Drake and Lawson, 2015), and the inability of many community gardens and farms to afford paid, skilled staff constrains both production

and programming (Cohen and Reynolds, 2015). Furthermore, urban gardening support

organizations struggle to meet the demand for technical assistance due to small staff size and

resources, and language and cultural barriers (Baker, 2004; Saldivar-Tanaka and Krasny, 2004;

Svendsen and Campbell, 2008; Krasny and Tidball, 2009). This leaves many gardeners eager for

further assistance in horticulture, garden organization and administration, community outreach

and networking, and program evaluation (Cohen and Reynolds 2015).

Urban gardens: Agroecological characteristics and challenges

In contrast to the well-documented social and institutional aspects of urban gardening,

agricultural production and ecological processes in food-producing spaces have only recently

received attention (Guitart et al., 2012). Insights from the broader field of urban ecology,

combined with initial work on the agroecological characteristics of urban gardens, suggest that

gardeners face challenges for sustainable food production, including soil quality concerns,

nutrient excesses, and unique insect pest pressures. Building soil quality is a challenge for urban

growers, who often plant in raised beds to create a suitable growing medium on compacted lots

and minimize exposure to soil contaminants (Clark et al., 2008; Witzling et al., 2010; Mitchell et

al., 2014; Pfeiffer et al., 2014,). The use of imported substrates (e.g., wood chips, clean fill) may

result in suboptimal soil structure, coarse textures, low water-holding capacity, and high

potential for nutrient leaching losses (Cameira et al., 2014; Pfeiffer et al., 2014). Furthermore,

nutrient applications in urban gardens are often excessive, leading to high levels of soil nutrients

which can be lost to the environment and cause nutrient imbalances for crop growth (Witzling et

al., 2010; Dewaelheyns et al., 2013; Cameira et al., 2014). Finally, studies of urban forests and

vacant lots show that cities have low arthropod natural enemy (predator and parasitoid)

populations and higher densities of herbivorous insect pests than surrounding rural areas (McIntyre, 2000; Pickett et al., 2001), which may decrease crop productivity and quality if the same trend holds in urban vegetable gardens.

Despite these challenges for food production and environmental quality, recent research also suggests that gardeners' management decisions may enhance ecological processes underlying urban food production. For example, gardeners may be able to augment arthropod natural enemy populations and biological control of insect pests by providing suitable non-crop habitat (Gardiner et al., 2014; Philpott et al., 2014). Ecologically-based soil management approaches such cover cropping could also be integrated into urban gardening practices. Cover crops provide many benefits in other agricultural systems, including improved soil quality and nutrient cycling (Wander, 2004; Snapp et al., 2005; Tonitto et al., 2006; Blesh and Drinkwater, 2013).

Increasing reliance on ecological processes in urban gardens could enhance ecosystem services and improve agricultural production while preventing negative environmental impacts. To contribute to the knowledge base for developing ecologically-based management practices tailored to urban gardens, we characterized food-producing community gardens in New York City (**NYC**). Through survey interviews with gardeners and systematic collection of ecological data, we explored three over-arching questions: 1) What are the agroecological and social characteristics of food-producing community gardens in NYC? 2) What are the key constraints to food production in NYC community gardens? 3) Are gardener knowledge systems adequately developed to overcome production challenges and what information sources do urban gardeners use to inform management decisions?

Methods

We used social and ecological data collection methods in a nested design to characterize 61 food-producing community gardens across NYC (Fig. 1.1). Of NYC's approximately 490
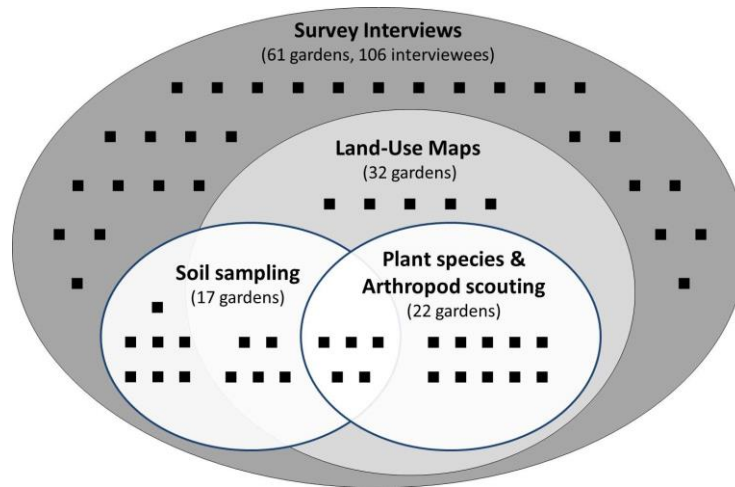
Fig. 1.1. Nested research design for characterizing 61 food-producing gardens in NYC. Each square represents one garden. Seven additional gardens (not within the survey interview dataset) are included in our land use, plant species, and arthropod scouting datasets.

community gardens, about 80% (392) host food production while 20% grow only ornamental plants (Gittleman et al., 2011). For our survey and subsequent ecological sampling, we selected gardens growing vegetables and fruits. Other food-producing spaces in the city include 350 institutional gardens (associated with the New York City Housing Authority and public schools), seven community farms, and three commercial farms (Cohen et al., 2012). Thus, while our findings represent only community gardens, some of our recommendations may provide useful insights for growers at other urban agriculture sites, particularly when they share key characteristics with community gardens (e.g., use of raised beds with imported soil).

The community gardens participating in this study represent about 15% of food-producing community gardens in the city and are located in all five of NYC's boroughs, with a distribution roughly proportional to the number of community gardens found in each borough.

To describe agroecological features of these gardens, we combined information from gardener interviews with ecological measurements of land use, soil properties, plant species richness, and arthropod communities. We relied on interviews with gardeners and fieldwork experiences to provide insight into gardening challenges, gardener knowledge systems, and social and organizational features of NYC gardens.

During the initial survey interview phase of the study, we worked with 61 food-producing community gardens administered by GreenThumb (www.greenthumbnyc.org), a program of the NYC Department of Parks and Recreation that provides materials and workshops for gardens. We then selected a subset of gardens for land-use mapping, plant species richness surveys and arthropod scouting. We chose sites where gardeners agreed to facilitate regular access for arthropod scouting, and to represent a range of land-use practices and landscape contexts (i.e., varying degrees of urbanization) that we hypothesized would affect arthropod communities. Finally, we sampled and analyzed soils from 17 Brooklyn gardens where gardeners and local organizations expressed interest in participatory research on cover crops and soil management.

Survey Interviews

From January 2010 through February 2012, we interviewed 61 garden coordinators and 66 gardeners using two distinct survey instruments. Given that almost all garden coordinators are also gardeners, we administered both surveys to some garden coordinators, resulting in 106 interviewees. Interviews were conducted in either English or Spanish, according to the interviewee's preference.

The survey for garden coordinators focused on general questions about the community garden, including: garden age and size, membership, languages spoken, types of garden beds and

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sources of soil and compost used to grow food crops, composting, and land tenure. The gardener survey contained more detailed questions about crops grown, gardening experience and practices, reliance on garden produce, information sources, knowledge and use of ecologically-based management practices, and socioeconomic and demographic information. Both surveys included questions about challenges to producing food in urban community gardens.

Garden land-use maps

For each garden selected for land-use mapping, we measured the areas devoted to four major categories of land-uses: 1) 'Agricultural crops' included annual food crops (primarily vegetables), and perennial food crops (fruit trees, berry bushes, asparagus, etc.). 2) 'Ornamental plants' included annual and perennial flowers and woody perennials (shade trees and shrubs). 3) 'Food production infrastructure' consisted of land-uses supporting food production, including paths to facilitate food crop maintenance, compost bins, rainwater harvesting tanks, and structures (toolsheds, chicken coops, and beehives). 4) 'Open/Recreational areas' included open grassy areas, recreational structures (e.g., gazebos, stages), and other non-gardening areas (e.g., picnic areas).

Using measurements from our site surveys, we constructed scale maps showing the land-uses in each garden. A small percentage of land in some gardens (average = 2%) was in rubble (leftover from the vacant lots where most gardens were created) or weeds. We subtracted this 'unmanaged' area from total garden area and then calculated the percentage of each garden devoted to each land-use.

Soil properties

We took soil samples from 266, 1.9-m^2 (20-ft^2) research plots in 17 Brooklyn gardens. Samples were collected in August and September of 2011 and 2012. For each plot, we collected 8-9 soil cores (2 cm diameter by 20 cm depth, except where the depth of the raised bed was < 20 cm) and composited them for processing and analysis. Composite samples were air-dried and then passed through a 2-mm sieve prior to analysis.

Representative subsamples of each soil were sent to the Agricultural Analytical Services Laboratory at Penn State University (University Park, PA) for measurements of soil particle size, pH, and available phosphorous (P), potassium (K), magnesium (Mg), and calcium (Ca). Samples were analyzed for particle size using the hydrometer method (Gee and Bauder, 1986). Available P, K, Mg, and Ca were determined using the Mehlich 3 (ICP) method (Wolf and Beegle, 1995). To determine total C and N content, we roller-ground representative subsamples of each soil and analyzed them by dry combustion using a LECO 2000 CN Analyzer (LECO Corporation, St. Joseph, MI).

We also selected a subset of soil samples for more intensive characterization: 36 plots from four gardens in 2011, and 54 plots from six gardens in 2012. In these plots, we measured bulk density, soil water content at field capacity (g water/g moist soil, expressed as **%H$_2$O**), and the C and N contents of particulate organic matter (**POM**; organic matter > 53 μm, usually derived from recent inputs). We took triplicate measurements of bulk density and soil water content at field capacity in each plot using gravimetric methods. Samples of known volume were weighed moist in the field 48 hours after wetting with a standard volume of water, dried at 60°C for 48 hours, and re-weighed. We calculated bulk density and soil water content at field capacity as follows:

$$\text{Bulk density} = \frac{\text{g field moist soil}}{\text{soil volume (cm}^3)}$$

$$\% \; H_2O, \text{field capacity} = \frac{(\text{g field moist soil} - \text{g oven dry soil})}{\text{g field moist soil}}$$

We extracted POM fractions from the soils using the size and density separation method presented in Mariott and Wander (2006a) with slight modifications to accommodate the large quantity of free POM in raised-bed soils constructed with a high proportion of compost (Chapter 2). We then analyzed each POM fraction for C and N by dry combustion, as outlined above.

Plant species richness inventories

In each garden participating in arthropod scouting (see below), we identified and tallied the number of species of agricultural plants, ornamental plants, and weedy plants (not sown or tended by gardeners). Knowledgeable gardeners at each site and horticulturalist C. Day assisted with plant identifications; we also consulted references to confirm ornamental and weedy plant identifications (Uva et al., 1997; Day, 2007; del Tredici, 2010).

Arthropod scouting

Based on discussions with gardeners and consultation with an Extension educator (J.M. Ameroso), we adapted scouting procedures used for integrated pest management on commercial farms to characterize arthropod pest and natural enemy populations and pest damage on crops (Nihoul et al., 1991; Seaman et al., 2000; Castagnoli et al. 2003). We focused on three crop families: Brassicaceae ('Brassicas,' e.g., collards, kale, cabbage, bok choy), Cucurbitaceae ('Cucurbits,' e.g., cucumber, summer squash, and winter squash), and Solanaceae (tomatoes).

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From June through September of 2011 we collected scouting and yellow sticky card data on

these crop families in 22 community gardens. During each garden visit, we examined ten

randomly selected Brassica, Cucurbit, and tomato plants and recorded information on arthropod

pests and natural enemies present using standard scouting procedures (Table 1.1).

Table 1.1. Arthropod pests and natural enemies (predators and parasitoids) monitored and metrics used to characterize their populations. All metrics were calculated from garden-level averages (i.e., the average per-plant arthropod population or damage index across the 10 plants scouted in each garden). For pests, we report metrics from the scouting week in which each pest reached its seasonal peak. For natural enemies, we report average metrics across all scouting weeks.

Arthropod common name	Scientific name(s)	Population metrics reported
BRASSICA PESTS		
Whiteflies	Homoptera: Aleyrodidae	# whitefly pupae/leaf [a]
Aphids	*Aphis gossypii, Myzus persicae*	# aphids/plant
Flea beetles	*Phyllotreta spp.*	# flea beetles/plant
Lepidopteran larvae	Lepidoptera	# larvae/plant
CUCURBIT PESTS		
Aphids	*Aphis gossypii, Myzus persicae*	# aphids/10 leaves
Squash bugs	*Anasa tristis*	# nymphs/10 leaves
TOMATO PESTS		
Aphids	*Aphis gossypii, Myzus persicae*	# aphids/leaf [b]
Two-spotted spider mite	*Tetranychus urticae* Koch	Spider mite leaf damage index/plant [c]
NATURAL ENEMIES		
Ladybird beetles	Coccinellidae (e.g., *Coccinella septempunctata, Stethorus punctum*)	# ladybird adults and # larvae/plant
Syrphid fly larvae	Diptera: Syrphidae	# syrphid fly larvae/plant
Lacewing larvae	*Chyrsoperla oculata*, etc.	# lacewing larvae/plant
Minute pirate bugs	*Anthocoridae* (e.g., *Oris insidiosus*)	# minute pirate bugs/plant
Parasitic wasps	Hymenoptera	# parasitic wasps/plant (sticky cards)[d]
Spiders	Araneae	# spiders/plant

[a] Average of three leaves

[b] Average of three randomly selected complete (compound) leaves, one from each third of the plant (upper, middle, and lower) (Seaman et al. 2000).

[c] The Leaf Damage Index (**LDI**) is a score of the intensity of visual damage from spider mite feeding on a tomato leaf. It ranges from 1 to 5, with 1 representing < 10 % damage and 5 representing 80-100% damage to the leaf. These visual assessments of leaf damage have been shown to be a closely correlated with spider mite abundance and population structure on tomato plants (Castagnoli et al. 2003, Nihoul et al. 1991). For each plant scouted, we averaged the LDIs from three randomly selected complete leaves, one from each third of the plant.

[d] Average of 2 yellow sticky cards per plant family per garden in each scouting week.

To monitor parasitic wasps, we also placed six yellow sticky cards (two per crop family) within 15 cm of the plant, 15 cm above the ground. After 48 hours, we collected the cards, covered them with saran wrap, and froze them for later identification and counting of parasitic wasps under a microscope. Table 1.1 summarizes the arthropod pests and natural enemies scouted on each crop, scouting protocols and population metrics reported.

Data analysis

We analyzed data from interviews and ecological sampling using JMP Pro 11 statistical software (SAS Institute, Cary, NC). For interview data, we compiled basic descriptive statistics from gardeners' responses to all questions. We also investigated questions about gardener motivations and knowledge by examining relationships between key categories of information. To determine if gardeners experiencing economic stress relied on garden produce to a greater extent than other gardeners, we compiled data from questions about reliance on garden produce by food security status (food insecure or food secure)[1] and household income bracket (less or greater than $50,000/year). We coded gardeners' responses to open-ended questions about crop rotation and cover cropping to characterize their knowledge and use of ecologically-based management practices. To evaluate if gardeners practiced adequate crop rotation, we analyzed sequences of crops planted in a particular bed over at least three years, as reported by gardeners (n=24). We defined "adequate crop rotation" as crop sequences that do not repeat plant families more than once every three years, which is considered effective for disease management in most cases

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[1] For this analysis, food insecurity was indicated by a "yes" response to at least one of three interview questions (all relating to food security or insecurity in the past year): (1) if the gardener had worried that her/his household would not have enough food, (2) if the gardener or other household member had been unable to eat sufficient fruits and vegetables due to lack of resources, and/or (3) if the gardener or other household member ate smaller meals or less frequent meals than s/he would have preferred due to lack of resources.

(Mohler and Johnson, 2009).

For land-use and arthropod populations, we calculated summary statistics from garden-level data. We calculated summary statistics for soil properties from beds (management units) sampled within each garden, and report averages by garden. We also used univariate and multiple regression models to assess relationships among soil properties at the plot level. Where scatterplots suggested nonlinear relationships between soil properties, we fitted appropriate curves using the Nonlinear Regression platform in SigmaPlot 10 (Systat Software, San José, CA).

To explore potential influences of garden size and neighborhood socioeconomic status on land-use allocation at the garden level, we ran simple regressions. Predictor variables (in separate regressions) included total garden area and median household income in the ZIP code where each garden is located. Response variables included area and percent garden area in vegetable crops, ornamental plants, and recreational areas. ZIP codes were determined from garden addresses given in the Open Accessible Space Information System (http://www.oasisnyc.net/). Median household income was obtained for each ZIP Code Tabulation Area from the U.S. Census Bureau's American FactFinder (http://factfinder2.census.gov), Selected Economic Characteristics as estimated by the 2008-2012 American Community Survey.

Results

Agroecological characteristics and gardener practices

Garden size and land-use

Community gardens in New York City are relatively small. Forty percent of gardens where we

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conducted interviews were under 500 m^2 (0.12 acres) and nearly 70% measured less than 1000 m^2 (0.25 acres) (Fig. 1.2).
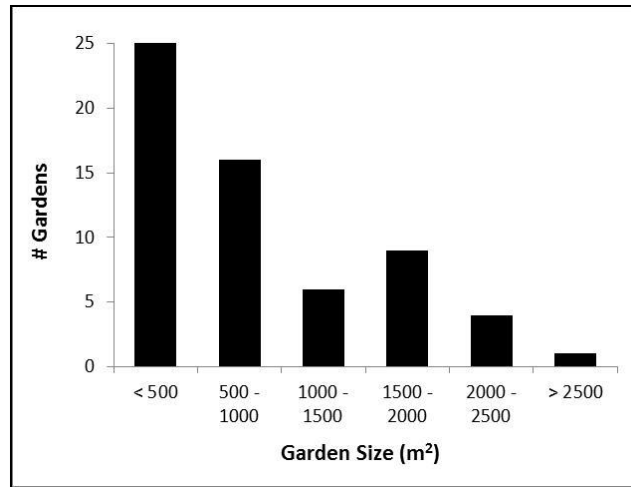
Fig. 1.2. Histogram of garden sizes (n=61).

Gardens contained agricultural crops, food production infrastructure (mainly paths for maintaining food crops), ornamental plants, and open/ recreational areas (Figs. 1.3, 1.4, and 1.5). While allocation of land to different uses varied across gardens (Fig. 1.3), gardeners devoted the greatest proportion of garden area to food production. On average, food crops and supporting infrastructure occupied nearly half of garden area, more than any other land-use (Fig. 1.4). Almost all agricultural crop area was annual vegetables, with little area in perennial crops (Fig. 1.4). Since almost 70% of gardens did not use cover crops between annual cropping cycles (data not shown), most agricultural crop area is bare over the winter. Area in paths was positively correlated with agricultural crop area (r^2_{adj}=0.93, p<0.0001; data not shown). On average, gardeners maintained little area in flowers (12%) and woody perennials (9%), though some gardens did maintain substantial ornamental plant areas (1.3 and 1.5). Areas devoted to

recreation and community gatherings composed just over one-third of garden area, on average (Figs. 1.3 and 1.4).
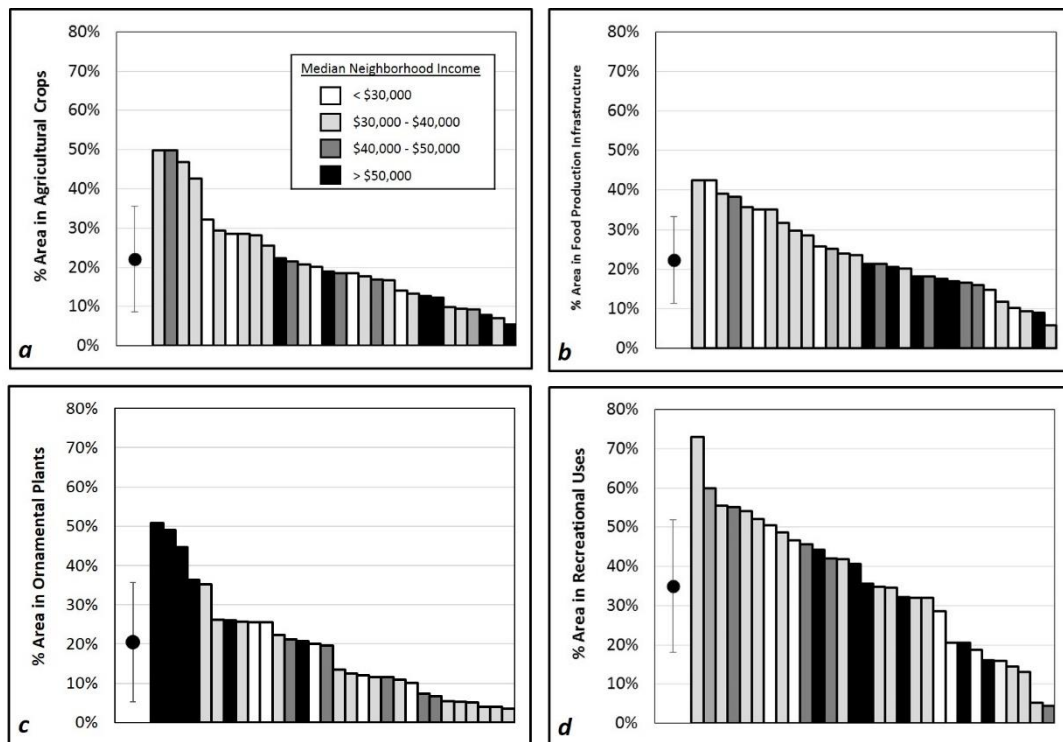
Fig. 1.3. Percent area allocated to four categories of land uses in mapped gardens varying in median neighborhood income: a) agricultural crops, b) food production infrastructure (mainly paths), c) ornamental plants, and d) recreational areas. The dot represents the average allocation to each land use and standard deviation. Each bar represents percent area allocated to a given category in a single garden. Bars are color-coded by median household income in the neighborhood where the garden is located: white, < $30,000; light gray, $30,000 - $40,000; dark gray, $40,000 - $50,000; black, > $50,000.
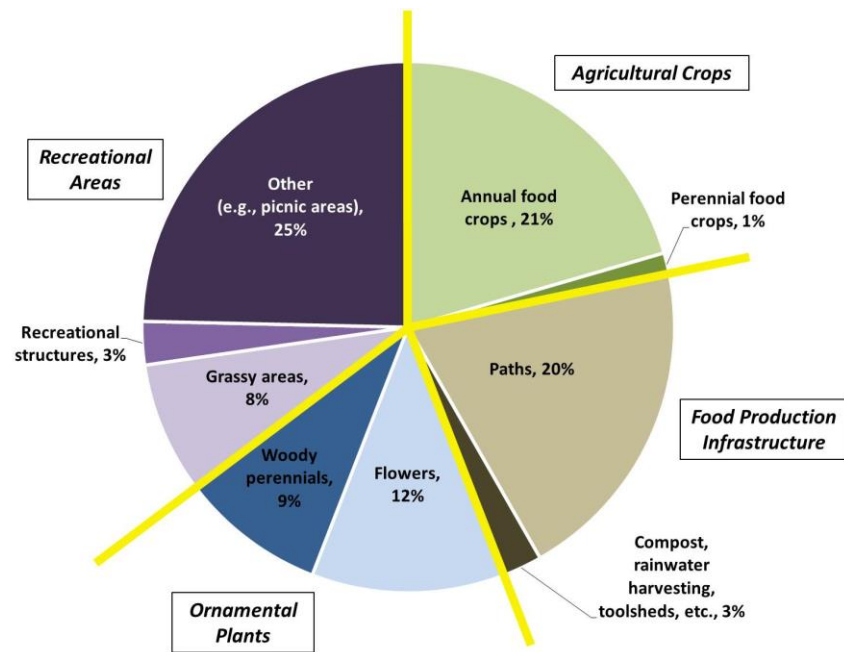
Fig. 1.4. Pie chart showing a detailed breakdown of the average percent allocation to different land uses within the major categories of agricultural crops (green shading), food production infrastructure (brown shading), ornamental plants (blue shading), and recreational uses (purple shading)
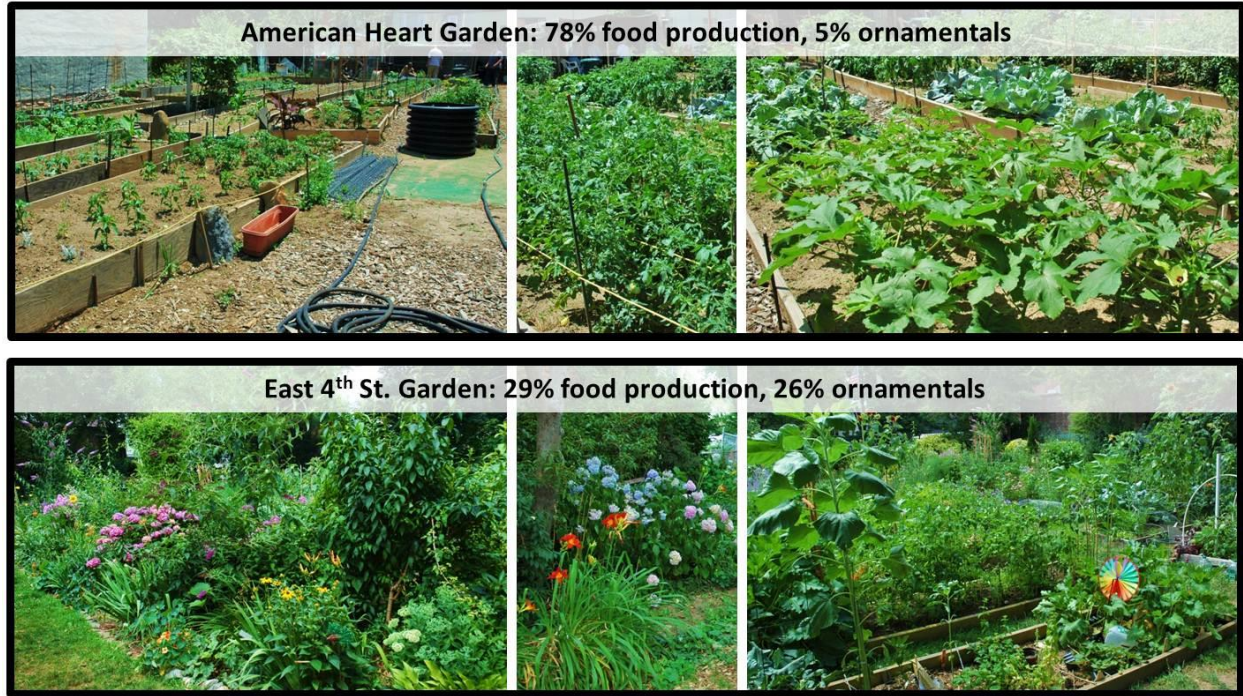
Fig. 1.5. Photos from two gardens with contrasting land-use patterns. While the American Heart Garden (top) emphasizes vegetable production and contains few ornamental plants, the East 4th St. Community Garden (bottom) has less area devoted to vegetable production and large borders of perennial trees and flowers.

Factors influencing allocation of garden space varied for different land-uses. There were few clear patterns in land-use allocation based on total garden area or median income in the surrounding neighborhood, with several exceptions. Total garden area was not correlated with the percentage of garden area devoted to vegetable crops, ornamental plants, or other non-gardening areas, or with ornamental plant area. Garden size significantly influenced vegetable crop area (r^2_{adj}=0.75, p<0.0001) and area devoted to paths for maintaining vegetable crops (r^2_{adj}=0.85, p<0.0001). Thus, large gardens had more area in vegetable crops and associated paths compared to small gardens, but did not host larger areas of ornamental plants. Median income in the garden neighborhood was positively correlated with the percentage of garden area in ornamental plants (r^2_{adj}=0.47, p<0.0001) and (weakly) negatively correlated with the percentage of garden area in vegetable crops (r^2_{adj}=0.13, p=0.027).

Crops Grown

Food crop areas in NYC gardens are dominated by crops in the Solanaceae, Cucurbitaceae, and Brassicaceae families. When we asked gardeners to list their "six most important crops," seven of the ten most frequently cited crops belonged to these three families (Fig. 1.6).
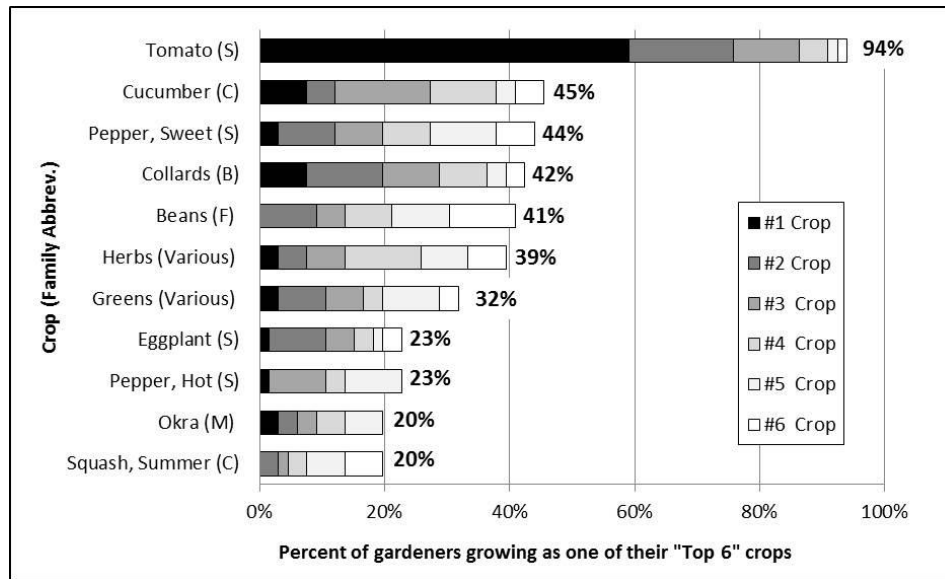
Fig. 1.6. Most common crops in NYC gardens and the percentage of gardeners growing each as one of their "six most important" crops (n=66). Plant family abbreviations (in parentheses) are: S=Solanaceae; C=Cucurbitaceae; B=Brassicaceae; F=Fabaceae; M=Malvaceae.

Tomatoes were by far the dominant crop, appearing on 94% of gardeners' lists. However, despite the dominance of several plant families, gardeners in NYC collectively grow a wide variety of crops. Gardeners' "top six" lists included 37 crops, and our plant species inventories documented an average of 43 agricultural crops per garden (range, 18-70) and nearly 100 food crops across the 22 surveyed gardens. These included ethnic specialties such as bitter melon (*Momordica charantia*), long beans (*Vigna unguiculata subsp. sesquipedalis*), luffa or sponge gourd (*Luff*a spp.) and Malabar spinach (*Basella alba*), among others.

Soil sources, management and properties

Ninety-one percent of the gardeners we interviewed grew food crops only in raised beds (Table

1.2). Most gardeners used amendments to improve soil quality and to provide nutrients for

vegetable crops, most commonly compost from GreenThumb or the garden (Table 1.2).

Table 1.2. Soil sources and management in NYC community gardens (n=66). Percentages of gardeners using particular soil amendments add to > 100%, since many gardeners use multiple amendments.

Soil management practice	% Gardeners	Notes/Examples
Garden beds		
Raised beds	91%	Constructed with clean fill & compost (78%) or clean fill only (22%)
In ground	6%	
Raised beds & in-ground	3%	
Soil amendments		
Compost	58%	Compost from GreenThumb or the garden
Chemical fertilizers	24%	Miracle-Gro
Manure	24%	Horse manure from stables
Organic fertilizers	20%	Granular organic fertilizers, blood meal, fish emulsion
Topsoil	17%	Bagged topsoil from Home Depot
Mulch	9%	Straw, leaf mold

Selected soil properties for raised-bed Brooklyn garden soils are summarized by garden

in Table 1.3. Most soils were sandy loams or loamy sands, with a slightly alkaline pH and very

high nutrient levels. Brooklyn garden soils also had high average total C and N, though C and N

levels varied widely (Table 1.3). On average, POM accounted for nearly half of total soil C and

N reserves, and free POM (POM not associated with soil aggregates, usually from very recent

organic inputs) accounted for approximately three-quarters of POM-C and –N (data not shown).

These soils generally had very low bulk densities (range, $0.54 - 1.61$ g/cm^3) and water contents

at field capacity (range, $0.15 - 0.40$ g H$_2$O/g moist soil).

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Table 1.3. Summary statistics for soil properties measured in cover crop research plots in 17 Brooklyn gardens. Data on texture (% sand, % clay), pH, P, K, Total C, and Total N are based on 157 beds containing 266 research plots, sampled in the Fall of 2011 and 2012. Data on bulk density and % H₂O (water content at field capacity) are based on triplicate samples from a subset of 57 beds containing 90 research plots across six gardens, sampled in the Fall of 2011 and 2012.

Garden	% Sand	% Clay	pH	P (mg/kg)	K (mg/kg)	Soil C (g/kg)	Soil N (g/kg)	Bulk density (g/cm³)	% H₂O, field capacity (g H₂O/g moist soil)	# beds / samples
1	69.7	10.8	7.1	123.0	498.3	77.1	4.5	------	------	4 / 4
2	66.7	9.6	6.9	470.5	391.5	67.2	4.2	------	------	2 / 2
3	72.8	11.0	7.4	209.6	272.6	62.5	3.4	------	------	5 / 5
4	63.4	10.6	7.2	314.0	134.6	35.8	2.3	------	------	5 / 12
5	74.9	10.4	7.2	190.7	367.3	136.2	7.0	------	------	3 / 3
6	69.9	11.1	7.0	234.6	155.2	109.8	7.1	0.95	0.24	10 / 40
7	61.1	14.7	7.2	179.7	181.8	37.6	1.6	1.37	0.19	29 / 59
8	65.0	9.7	7.5	139.7	140.8	29.0	1.0	------	------	3 / 8
9	73.7	9.6	7.1	272.7	160.7	59.1	4.0	0.87	0.27	32 / 32
10	77.6	10.0	6.7	152.0	104.0	21.5	1.3	------	------	1 / 3
11	70.4	9.9	7.4	185.5	117.8	42.6	2.0	1.11	0.21	21 / 21
12	75.3	5.0	7.1	216.1	202.7	102.6	5.7	0.88	0.29	10 / 23
13	64.5	11.3	7.3	292.8	316.3	50.8	2.7	------	------	21 / 21
14	67.3	9.9	7.0	290.6	113.7	74.7	3.9	1.05	0.29	4 /21
15	69.6	7.4	7.1	353.3	165.7	29.6	1.5	------	------	3 / 5
16	77.5	9.6	6.3	59.0	63.0	17.6	0.5	------	------	1 / 3
17	76.6	5.0	7.0	340.7	238.7	71.4	3.9	------	------	3 / 3
Overall	**68.7**	**10.6**	**7.2**	**235.6**	**199.2**	**58.2**	**3.3**	**1.0**	**0.25**	**157 / 266**

Soil texture and pH were consistent across gardens, while properties that respond strongly to management (i.e., nutrients and organic matter) showed high variability. Reflecting the fact that most gardeners grow crops in 'constructed' soils, texture was consistently sandy; the overall coefficient of variation (**CV**) for percent sand was only 10%. Soils in this concrete-rich, urban environment also had consistently neutral-to-alkaline pH levels (overall CV=3%). In contrast, nutrient levels and organic matter-related soil properties showed large variation at all spatial scales (across gardens, within gardens, and within beds). For these properties, variation between different sampling areas in the same bed was only slightly smaller than variation between beds in the same garden, indicating that urban garden soils are heterogeneous at fine scales. For example, total C had average CVs of 21% within beds, 28% within gardens, and 60% overall. POM-C was even more variable, with average CVs of 29% within beds, 41% within gardens, and 92% overall (data not shown).
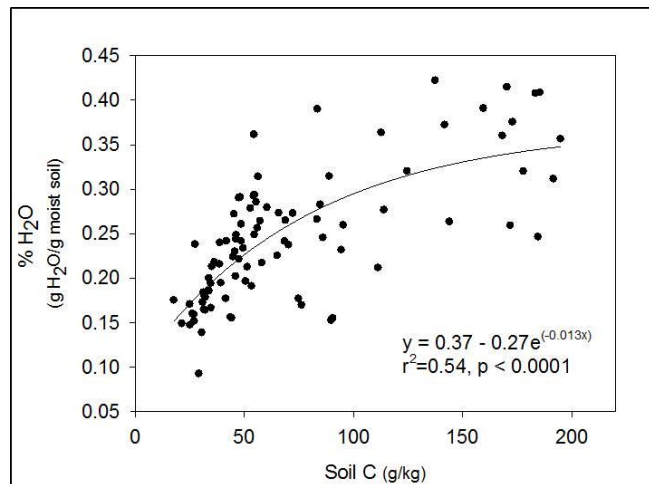
Fig. 1.7. Relationship between total soil C and water content at field capacity (g H_2O/g moist soil) for 90 research plots across six Brooklyn gardens, sampled in the Fall of 2011 and 2012

Soil organic matter content impacted several related soil characteristics which support plant productivity. Total soil C showed significant, positive relationships with total N, Mg, Ca, and CEC, but not with P or K (data not shown). Soil water content at field capacity increased exponentially with total soil C to an upper limit of ~0.37 g H_2O/g moist soil (Fig. 1.7). Sand content did not exhibit a significant correlation with water content, at least over the range found in the subset of plots selected for field capacity measurements (56 - 88% sand).

Arthropod management and populations

The most common insect management strategy – used by 32% of gardeners -- was application of a 'natural' pesticide or repellent (e.g., soap and water, cayenne pepper) (Table 1.4). Repellent crops, primarily marigolds, were the second-most common strategy with 29% of gardeners, although many expressed doubt about their efficacy. Interestingly, 27% of gardeners did not take any steps to manage insect pests, although this was one of the most commonly cited challenges for growing food (see below, 'Constraints to urban food production').

Table 1.4 Insect management strategies used by community gardeners in NYC (n=66).

Insect management practice	% Gardeners	Examples
Natural / botanical pesticide or repellent	32%	Soap & water, essential oils (peppermint, rosemary, etc.), vinegar & water, lime, ashes, garlic, cayenne pepper, baking soda & water
Repellant crops	29%	Marigolds, basil, nasturtium, herbs (rosemary, lavendar, etc.)
None	27%	
Hand-picking	18%	
Chemical pesticide	11%	Boric acid, pyrethrin, various unknown powders or sprays from local hardware stores
Biocontrol agents	5%	Praying mantis, ladybugs

Table 1.5 Summary statistics for arthropod pests and natural enemy populations, measured with scouting and sticky cards in 22 gardens during the summer of 2011. All pest insect metrics were calculated from garden-level average per-plant insect populations during the week in which each pest population reached its peak. All natural enemy population metrics were calculated from garden-level average per-plant or per-sticky card populations over the entire season.

Arthropod common name	Metric	Average ± SE	Range	% Gardens Exceeding Threshold [a]
BRASSICA PESTS				
Whiteflies	# pupae/leaf	15.8 ± 3.3	0.2 - 57.9	91%
Aphids	#/plant	8.7 ± 3.6	0.2 - 75.2	100%
Flea beetles	#/plant	5.8 ± 1.9	0.0 - 34.9	33%
CUCURBIT PESTS				
Aphids	#/10 leaves	25.3 ± 4.4	1.4 - 64.7	100%
Squash bug nymphs	#/10 leaves	0.9 ± 0.3	0.0 - 5.8	29%
TOMATO PESTS				
Aphids	#/leaf	4.2 ± 0.9	0.6 - 19.0	18%
Two-spotted spider mites	Mean LDI	3.6 ± 0.2	1.5 - 4.8	100%
NATURAL ENEMIES				
Scouted natural enemies,[b] Brassicas	#/plant	0.4 ± 0.1	0.0 - 1.5	n/a
Scouted natural enemies,[b] Cucurbits	#/10 leaves	0.9 ± 0.1	0.0 - 2.4	n/a
Scouted natural enemies,[b] Tomatoes	#/plant	0.4 ± 0.1	0.0 - 1.5	n/a
Minute Pirate Bugs	#/sticky card	6.3 ± 1.0	0.0 - 16.8	n/a
Parasitic Wasps	#/sticky card	72.7 ± 7.0	32.8 - 139.5	n/a
Natural enemy: Pest (sticky cards)	ratio	0.61 ± 0.04	0.28 - 0.96	n/a

[a] Thresholds are pest populations at which pest control actions are recommended to prevent economic losses and are as follows: whitefly nymphs on $\geq$ 40% of Brassica leaves (Diehl et al. 1997); 1 aphid/10 Brassica plants (Dimson 2001); 2 – 5 flea beetles/Brassica plant (Grubinger 2005) ; aphids on $\geq$ 20% of Cucurbit runners (Reiners and Petzoldt 2014); $\geq$ 1 squash bug egg mass/Cucurbit plant (Reiners and Petzoldt 2014); 6 aphids/tomato leaf (Reiners and Petzoldt 2014); mean spider mite Leaf Damage Index (LDI) of 2.0 – 2.5 (Nihoul et al. 1991).

[b] Scouted natural enemies include (in decreasing order of overall abundance): minute pirate bugs, spiders, ladybird beetles, syrphid fly larvae, lacewing larvae.

Summary statistics for arthropod pest and natural enemy populations are reported in

Table 1.5. In general, pest populations were high, while natural enemy populations were

relatively low. Peak populations of whiteflies and aphids on Brassica crops and aphids on

Cucurbit crops greatly exceeded action thresholds[2] in 90-100% of gardens. All gardens also showed leaf damage from two-spotted spider mite feeding in excess of action thresholds. Insect pests that were problematic in some gardens, but not others, included: flea beetles on Brassicas, squash bugs on Cucurbits, and aphids on tomatoes. Arthropod predators were rare, with an average of less than one per plant. Minute pirate bugs and spiders were the most commonly observed natural enemies during scouting. Sticky card data also indicated substantial numbers of parasitic wasps.

Social garden characteristics

<u>Garden age</u>

All of the gardens in our study, with one exception, were founded after 1970. More than 80% were started after 1980, with the greatest number (41%) established during the 1990's.

<u>Gardener characteristics</u>

A wide variety of people of differing experience levels, incomes, and ethnicities participate in community gardening in NYC. As might be expected in gardens with culturally diverse membership, most gardens where we conducted interviews hosted multiple languages. Ninety-three percent hosted at least two languages, with 41% hosting three or more. Some gardens had up to seven languages represented. The most commonly spoken languages were English (found in 100% of gardens), Spanish (89%), Mandarin (16%), French (15%), and Creole (11%).

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[2] An action threshold is the "point at which pest populations… indicate that pest control action must be taken," and corresponds to pest populations that, left unchecked, will cause economic damage (U.S. EPA 2012).

Contributions of community gardens to food security and nutrition

While community gardens are not the only sources of produce for gardeners, they supply a substantial portion of gardeners' produce needs (Table 1.6). During the growing season, 55% of gardeners harvested more than two-thirds of the vegetables eaten in their households from their community gardens, and 22% harvested between one- and two-thirds of their household's produce needs.

Table 1.6. Reliance on garden produce by food security status and annual household income. Percentages of gardeners giving particular responses were calculated separately for food security status (food-insecure and food secure gardeners) and for annual household income level (less or greater than $50,000).[a]

Food security status / Household income →	Food-insecure (n=19)	Food-secure (n=47)	< $50,000/yr (n=42)	> $50,000/yr (n=17)	Overall (n=66)
% of household vegetable consumption from garden during the GROWING SEASON					
Less than 1/3	21%	24%	21%	31%	23%
1/3 - 2/3	16%	24%	24%	25%	22%
More than 2/3	63%	52%	55%	43%	55%
% of household vegetable consumption from garden during the WINTER					
Less than 1/3	68%	89%	88%	81%	83%
1/3 - 2/3	32%	7%	10%	19%	14%
More than 2/3	0%	4%	2%	0%	3%
Community garden ranking as OVERALL produce source					
Primary produce source	37%	23%	29%	19%	27%
2nd produce source	53%	49%	57%	38%	50%
3rd produce source	5%	21%	12%	25%	17%

[a] Response percentages by income level were calculated out of the total number of gardeners who chose to report their annual household income (n=59); this is lower than the total number of interviewees (n=66).

Gardeners reporting food insecurity or annual household income below $50,000/year showed slightly greater reliance on garden produce compared to food-secure and higher-income gardeners. A greater percentage of gardeners struggling with food insecurity relied on their

gardens for more than two-thirds of their vegetables during the growing season compared to food-secure gardeners (63% vs. 52%) and more than one-third of their vegetables during the winter (32% vs. 11%). Ninety percent of food-insecure gardeners ranked their garden as their first or second produce source, compared to 72% of food-secure gardeners. We found similar patterns for gardeners living on low incomes compared to higher-income gardeners (Table 1.6).

Constraints to urban food production

While many NYC gardeners grow enough produce to make important contributions to food security and nutrition, they face many challenges for agricultural production. The most commonly cited challenges among gardeners we interviewed included: building and maintaining soil quality and fertility, insect pest damage, weed management, limited time for gardening, reliable access to water, and mammalian pests (Fig. 1.8). Specific insect pest problems frequently mentioned by gardeners or observed in subsequent fieldwork are outlined in Table 1.7.
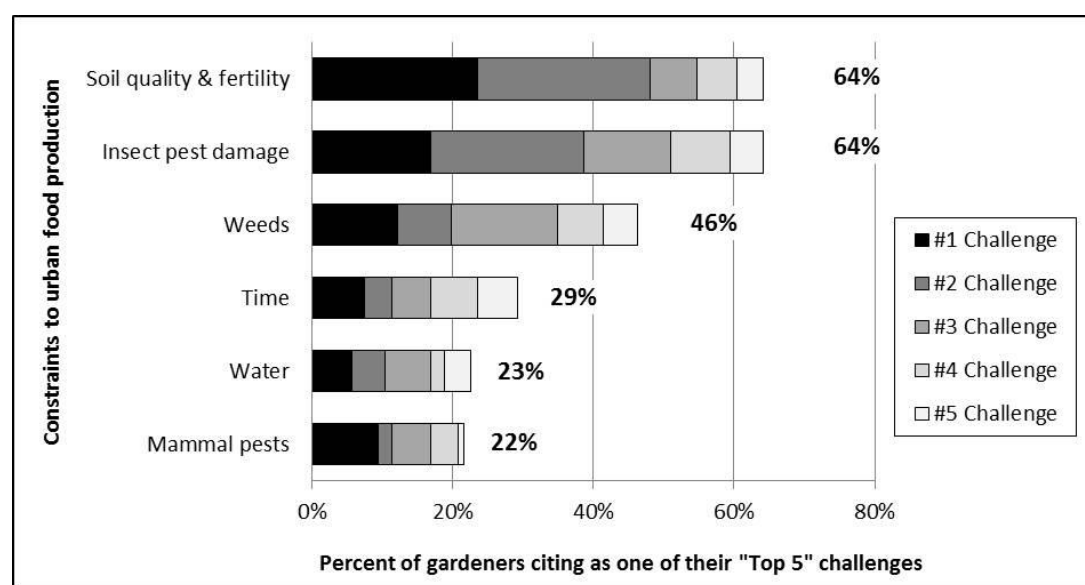
Fig. 1.8. Most commonly cited challenges for growing food in NYC community gardens and the percentage of gardeners citing each as one of their "top five" challenges (n=106)

Table 1.7. Commonly mentioned or observed insect pest problems in NYC community gardens, 2010-2011.

Insect common name	Insect scientific name	Crop hosts
Whiteflies	Homoptera: Aleyrodidae	Brassica crops, especially collards
Flea beetles	*Phyllotreta* spp.	Brassica crops, Eggplant
Lepidopteron larvae, e.g.: • Imported cabbageworm • Diamondback moth • Cabbage looper	Lepidoptera, e.g.: • *Pieris rapae* • *Plutella xylostella* • *Trichoplusia ni*	Brassica crops, esp. collards and cabbage
Squash bugs	*Anasa tristis*	Cucurbit crops
Squash vine borer	*Melittia cucurbitae*	Cucurbit crops, especially summer squash / zucchini
Two-spotted spider mite	*Tetranychus urticae* Koch	Tomatoes
Aphids	Homoptera: Aphididae	Many crops

Gardener knowledge systems

Knowledge & use of ecologically-based management practices

We used questions about crop rotation and cover cropping to provide insight into gardeners'

understanding and use of agroecological practices. Gardeners varied in their understanding and

use of crop rotation (Table 1.8). Eighty percent were familiar with the basic definition of crop

rotation (not planting the same crop in the same location year after year). However, only three

percent of gardeners understood the importance of rotating botanical families. Many gardeners

also struggled to articulate the multiple functions of crop rotation. The most commonly

understood function was to support soil fertility by avoiding repeated planting of heavy-feeding

crops. Only 5% of gardeners mentioned disease and insect pest management as potential

functions of crop rotation and none mentioned weed management, although crop rotation is a key

strategy for managing diseases, insects, and weeds (Liebman and Dyck, 1993; Mohler and

Johnson, 2009).

Table 1.8. Gardener knowledge and use of agroecologial management practices. Based on open-ended questions asking gardeners to define and list the potential benefits of crop rotation and cover cropping (crop rotation questions: n=66, cover cropping questions: n=102).

Agroecological practice / Knowledge & Use	% Gardeners
Crop Rotation	
Heard of crop rotation	80%
Practiced adequate crop rotation[a]	21%
Understands rotation of botanical families	3%
Identified functions of crop rotation:	
Soil fertility	65%
Pest control	5%
Disease suppression	5%
Weed management	0%
Cover Cropping	
Heard of cover crops	58%
Has used cover crops	29%
Identified functions of cover crops:	
Soil fertility	43%
Soil protection	15%
Weed suppression	8%
Soil tilth / structural improvement	5%

[a] Gardener's practice of "adequate crop rotation" was evaluated from the group of respondents who could remember a three-year sequence of crops planted in a particular management unit (n=24). We defined "adequate crop rotation" as crop sequences that do not repeat plant families more than once every three years, which is considered effective for disease management in most cases (Mohler and Johnson 2009).

These gaps in gardeners' understanding of crop rotation were reflected in their practices. Of all gardeners who could report a three-year sequence of crops planted in a particular bed (n=24), only 21% reported a sequence that did not repeat a plant family (Table 1.8). Even many gardeners who believed that they *did* practice crop rotation planted crops in the same family for multiple years, or with insufficient intervals for disease prevention. Of the gardeners who believed they were practicing crop rotation *and* could remember a three-year sequence of crops (n=13), 70% reported sequences that repeated a plant family in consecutive years (for example, pepper – tomato – eggplant, a sequence containing only Solanaceous crops) or waited only one

year before repeating a plant family.

As with crop rotation, many gardeners had heard of cover cropping (58%), but fewer gardeners used cover crops or understood their multiple functions (Table 1.8). Soil fertility was the most commonly identified function of cover cropping, recognized by 65% of gardeners. However, many gardeners did not realize that not all cover crops add nutrients (expressing, for example, the misconception that the non-legumes rye and wheat "put nitrogen back in the soil" when in fact only legumes fix nitrogen). Furthermore, very few gardeners (< 10%) recognized other functions of cover crops, such as weed suppression and improvement of soil tilth.

Gardening information sources

The most commonly used source of gardening information was other gardeners (59%), followed by websites (47%), print materials (41%), and GreenThumb workshops (30%) (data not shown). Interestingly, when we asked gardeners to name their preferred ways to obtain new information, workshops were the favorite by far (Fig. 1.9). Nearly half of gardeners identified workshops as the best way to obtain new information, and about 70% identified workshops as one of their top three choices. Print materials, talking with other gardeners, and websites were among the top three choices for about half of gardeners (Fig. 1.9).
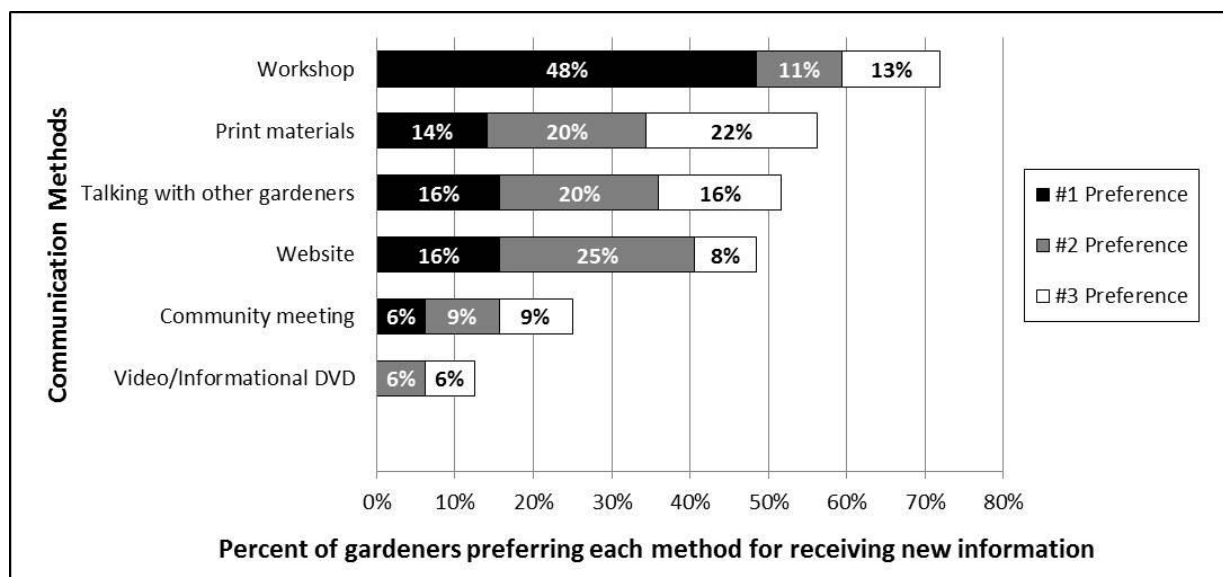
Fig. 1.9. Potential communication methods and the percentage of gardeners who chose each as their 1st, 2nd, or 3rd preference for getting new gardening information

Discussion

Taken together, our findings provide insight into the value of community gardens in urban neighborhoods, the unique characteristics of urban garden soils and arthropod communities that affect ecological processes in these gardens, constraints on food production and opportunities for addressing these problems. While food production and access are important for many urban community gardeners, these spaces also serve other functions that enhance quality of life in cities. The urban setting of NYC gardens imposes unique production constraints, including difficulties building soil quality in 'constructed' raised-bed soils, and landscape factors and environmental stressors that favor herbivorous pest populations over arthropod natural enemies. However, we see many opportunities for using agroecological practices to address these production challenges and expand ecosystem services in these gardens. To support gardeners in adapting agroecological practices to urban conditions, gardening educators can incorporate

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ecological knowledge and inquiry-based approaches in their programming.

Food production, gardener priorities, and social research needs

In keeping with other studies of urban settings, we found that community gardens are important sources of fresh produce in NYC. Gardeners devoted the greatest proportion of garden space to crops and supporting infrastructure, and relied on their gardens for a substantial amount of their families' fresh produce. These findings are consistent with studies documenting the productivity of urban community gardens; crop yields can sometimes exceed national averages for commercial vegetable production (Blair et al., 1991; Baker, 2002; Algert et al., 2006; Vitiello and Nairn, 2009; Gittleman et al., 2012). The significance of garden produce is two-fold. First, community gardeners achieve considerable cost-savings by growing their own produce (Armstrong, 2000; Saldivar-Tanaka and Krasny, 2004; Algert et al., 2006; Wakefield et al., 2007; D'Abundo and Carden, 2008). Second, our study and others have found that urban gardeners grow culturally significant crops that may be difficult to find or expensive elsewhere (Baker, 2004; Saldivar-Tanaka and Krasny, 2004; Shava et al., 2010). The fact that NYC gardens supply a significant proportion of gardeners' household produce needs is impressive, particularly in light of the unique challenges for agricultural production posed by the urban environment and lack of research and extension focused on urban agriculture (Guitart et al., 2012; Pfeiffer et al., 2014).

Given that garden produce was particularly important for food-insecure and low-income gardeners in NYC, our findings suggest that increased support for community gardens may improve food security in ways that foster the agency and dignity of individuals, families, and communities (Levkoe, 2006; Teig et al., 2009). Future research might explore how to design

effective programs and policies that enhance the capacity of community gardens to promote food security and nutrition. This research could identify essential technical and material assistance, as well as supportive funding and policy processes to ensure equitable distribution of resources that support gardening as a strategy to achieve community food security (Cohen and Reynolds, 2015).

While gardeners placed high value on the contributions of gardens to food access and better nutrition in their communities, the diversity of land-uses we documented in NYC gardens – including food production, ornamental plantings, and recreational spaces -- demonstrates that community gardens serve multiple purposes in urban neighborhoods. In addition to serving as a source of fresh produce, community gardens in NYC and other urban areas conserve green space and biodiversity and provide opportunities for recreation, cultural expression and socializing with neighbors (Blair et al., 1991; Armstrong, 2000; Saldivar-Tanaka and Krasny, 2004; Draper and Freedman, 2010; Shava et al., 2010). The variation in land-use allocation we observed suggests that the importance of these functions varies across gardens and depends on local context and community needs and interests (Drake and Lawson, 2015).

Several patterns in land-use were influenced by garden size and neighborhood income. The consistent increase in vegetable crop area with garden size may reflect widespread demand for food-growing space in NYC neighborhoods. In contrast, the percentage of garden area devoted to ornamental plants increased with neighborhood income rather than garden size. Gardeners in higher-income neighborhoods may be more able to afford -- and devote time to maintaining -- ornamental plantings compared to gardeners in lower-income neighborhoods, who may also prioritize other land uses (e.g., food-growing areas or recreational spaces). Our interview data on vegetable consumption suggest that lower-income gardeners rely on garden

produce to a greater extent than higher-income gardeners, and therefore may prioritize food production over other land uses. Furthermore, as median neighborhood income decreases, allocation of garden area to food production increases slightly, even within this subset of gardens selected for active food production areas. Had we included gardens dedicated solely to ornamental plantings (many of which are located in higher-income neighborhoods), the increased importance of food production in lower-income neighborhoods may have been more apparent. Recreational land-uses (e.g., picnic areas, grassy play areas) may also be more highly valued than ornamental plantings in lower-income neighborhoods if there are few other suitable areas for community gatherings or for children to play. This may be the case, as parks in poor areas tend to be smaller, more crowded, and have less amenities and more concerns regarding park quality and safety compared with parks in higher-income areas (Miyake et al., 2010; Vaughan et al., 2013).

Gardeners' land-use decisions are also likely shaped by factors that we did not investigate, such as the number of interested gardeners, physical constraints associated with available garden space (e.g., existing infrastructure, underlying concrete or shade from buildings), the time gardeners can devote to maintaining plantings, proximity of the neighborhood to other green spaces, and personal and cultural preferences. Thus, it is not surprising that space allocation in NYC community gardens varies among food production, ornamental plants, and recreational uses in ways that are nuanced and difficult to fully understand without more in-depth, qualitative methods.

Production constraints and potential agroecological solutions

Gardeners in NYC viewed soil quality and fertility and insect pests as the most important

problems impacting crop production in community gardens, and our data confirm that there are widespread challenges in both of these arenas. Our data also indicate that ecological properties and processes in these gardens differ from those in rural areas where most agricultural research has been conducted. Therefore, effectively addressing soil quality challenges in urban gardens requires understanding how the unique characteristics of raised-beds and constructed soils impact the cycling of organic matter, water, and nutrients. Similarly, an understanding of the environmental and management drivers of arthropod community composition should underlie efforts to address insect pest damage through cultural practices.

Farmers and researchers have developed agroecological approaches to improve soil quality and manage pests in commercial farming operations, and we see opportunities for adapting this knowledge to urban gardens. Agroecological management approaches are based on locally appropriate suites of practices that enhance biological processes (e.g., internal nutrient cycling, biological control of insect pests by predators and parasitoids) to support crop productivity and ecosystem health. This allows growers to avoid relying on expensive and environmentally damaging external inputs such as chemical fertilizers and pesticides (Kanyama-Phiri et al., 2008; Shennan, 2008).

Our interview results indicate that many NYC community gardeners have some knowledge of the ecological processes governing crop production, and, like gardeners in other cities, are motivated to minimize or avoid chemical use for health and environmental reasons (Armstrong, 2000; Wakefield et al., 2007; Carney et al., 2012). Furthermore, most gardens are intensively managed and some exhibit significant crop diversity. Thus, there is great potential for implementing agroecological management strategies. To tap this potential, researchers and educators should partner with gardeners to provide sustained technical assistance that supports

gardeners in effectively implementing, adapting, and refining agroecological practices to fit their urban setting and specific management goals.

<u>Start with the soil</u>

Fertile soil is the foundation of any agricultural endeavor, and urban community gardeners face formidable challenges in this arena because available garden sites are often contaminated with heavy metals and other toxins. To mitigate exposure to these contaminants, city gardeners usually construct raised beds with imported growing media (Shayler et al., 2009; Witzling et al., 2010; New York State Department of Health, 2011). Raised beds are often expensive to build (Witzling et al., 2010; Pfeiffer et al., 2014) and must be maintained with regular additions of soil and compost to keep contaminant concentrations low (Clark et al., 2008). As in other cities (Baker, 2004), gardeners in NYC cited access to clean soil and compost as a key production constraint, at times limiting the number of raised beds built when additional garden space was available (Cohen and Reynolds, 2015).

Even where gardeners can procure sufficient growing media, the unusual composition of raised-bed soils presents management challenges not found in natural soils. In NYC gardens, most raised beds are constructed with a mix of sandy clean fill and compost in varying proportions. Due to their coarse texture, these soils are well-drained but have poor water-holding capacity: Ninety-five percent of water-holding capacity measurements in our study were below the optimum level for preventing water limitation in sandy loam soils (~0.42 cm^3 H$_2$O/ cm^3 soil) (Brady and Weil, 2008). Cameira et al. (2014) also found that sandy textures in raised-bed allotment gardens in Lisbon were associated with low water-holding capacity and high potential for drainage and nutrient leaching.

Despite their sandy textures, community garden soils in NYC have high organic matter contents (approximately 12% on average[3]) due to the high proportion of compost mixed with the sand. Given the coarse textures and lack of silt and clay in these soils, the large SOM reserves likely play an even greater role in these soils than is typical for natural soils (Wander, 2004; Haynes, 2005, Marriott and Wander, 2006b, Po et al., 2009). For example, in Brooklyn garden soils, water content at field capacity increased exponentially with total soil C, whereas in natural soils both SOM and clay content influence water-holding capacity. High SOM levels cannot completely compensate for the lack of silt and clay in raised-bed soils, however. Most gardeners reported that their soils dry out quickly, despite the fact that 98% of beds had SOM levels in excess of the 4% SOM (2% C) level considered optimal for coarse-textured field soils (Gugino et al., 2009).

In addition to these impacts on soil structure and soil-water dynamics, very large SOM reserves in NYC garden soils lead to nutrient excesses, thus presenting another soil management challenge for gardeners. Total soil C showed positive correlations with N, Mg, and Ca, indicating that SOM reservoirs of these nutrients are of primary importance in these soils. In the plots we tested in Brooklyn, all P, Mg, and Ca values, and most K values, greatly exceeded optimum levels for vegetable production (NJAES, 2014). As such, they may cause nutrient imbalances for crops and environmental pollution. Our findings concur with other studies documenting excessive nutrient levels in urban garden soils. Researchers also found excessive P and K fertility in urban community gardens in Chicago (Witzling et al., 2010) and home vegetable gardens in Flanders (Dewaelheyns et al., 2013). In urban gardens in Lisbon, N inputs were two

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[3] This is based on our measurements of total soil C, which averaged 58.2 g/kg (~6% of soil mass), and the common 'rule of thumb' that SOM is approximately half carbon by weight (Brady and Weil 2008). Average SOM content in Brooklyn soils can therefore be estimated as 6% x 2 = 12%.

to three times higher than crop uptake, leading to N losses via leaching and denitrification (Cameira et al., 2014).

Clearly, NYC community gardeners face a dilemma. To improve soil structure and water-holding capacity, organic matter additions are recommended. However, in this case, adding composts (typically rich in nutrients) would exacerbate the nutrient excesses present in most gardens. Incorporating cover crops into urban gardens may improve soil-water dynamics and soil structure without adding nutrients (with the exception of legumes, which add new N through biological fixation). In the short term, cover crops could also be grown and the shoots used as surface mulch to retain soil moisture by reducing evaporation (Teasdale and Mohler, 1993). Over time, adding plant residues from cover crops to soils increases SOM levels (McDaniel et al., 2014), which is related to improved soil structure and water- and nutrient-holding capacity (Wander, 2004; Snapp et al., 2005). Furthermore, cover crops have dense root systems, and thus improve soil tilth and nutrient cycling through physical and biological processes associated with root growth and decomposition (Haynes and Beare, 1997). However, given that soil texture influences relationships between organic inputs, SOM levels, and soil function (Gentile et al., 2010), further research is needed to understand the long-term effects of cover cropping in these coarse-textured, raised-bed soils. Understanding how cover crop residue additions and residue management practices impact C and N accrual in organic matter fractions, aggregation, water-holding capacity and nutrient availability could inform recommendations for improving soil quality and fertility in raised beds through cover cropping.

Improved access to soil testing and guidance on appropriate use of soil amendments could also help address the problem of excessive nutrient levels and identify soils where nutrient levels are suboptimal. Facilitating soil testing and interpretation would allow gardeners to make

more informed decisions about when, and which, nutrient-containing amendments are needed to support crop production. Integrated social and ecological research might investigate the impact of providing assistance with soil testing, interpretation, and nutrient management planning on actual nutrient balances (the difference between nutrient inputs and exports in harvested crops) (Drinkwater et al., 2008) and environmental impacts of urban garden plots.

Unique challenges and strategies for pest management in NYC community gardens

Gardeners also cited insect pests among their top challenges for food production, and we found that pest populations are high enough to cause substantial crop damage and yield loss. This is consistent with previous studies of urban forests and vacant lots, which show that cities exhibit higher densities of herbivorous insects and reduced populations of arthropod natural enemies (predators and parasitoids) compared to surrounding rural areas (McIntyre et al., 2000; Cregg and Dix, 2001; Pickett et al., 2001). Our findings suggest that this pattern also holds in urban food-producing community gardens. The key drivers of severe pest pressure in urban settings may stem from 1) reduced plant diversity and abundance (both within gardens and in the surrounding landscape) which limit populations of natural enemies that would control pests, and 2) increased environmental stressors which allow pest species to proliferate.

Because predators and parasitoids need larger contiguous areas of high-quality habitat than herbivorous pests to gain enough food resources, natural enemies suffer more than pests in fragmented urban habitats (McIntyre, 2000; Gibb and Hochuli, 2002). In rural and sub-urban agricultural landscapes, large expanses of vegetation and diverse habitats (e.g., forested and riparian areas and hedgerows) provide natural enemies with shelter from environmental extremes, over-wintering sites, and food when pests are absent (Landis et al., 2000; Isaacs et al.,

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2009; Chaplin-Kramer et al., 2011). Such habitats are small and fragmented in urban environments, thus reducing the resources available to support arthropod predators and parasitoids. Generally low floral and woody perennial cover in many community gardens may further exacerbate the negative effect of habitat fragmentation on these taxa, leading to low abundance and diversity of natural enemies that would otherwise regulate pest populations (Gardiner et al., 2014).

Floral and woody perennial plantings can be used to restore natural enemy populations and promote biological control in agricultural systems, provided that suitable plant species are chosen – that is, species that are attractive to arthropod predators and parasitoids and provide critical resources at the right points in their life cycles to support optimal survival and reproduction (Fiedler and Landis, 2007a; Fiedler and Landis, 2007b). Most studies showing an increase in natural enemy populations with such 'habitat management' efforts have taken place on rural farms. For example, borders of undistributed vegetation around field edges serve as refuges for insect predators such as ladybird beetles, spiders, and predatory mites (Mohler and Johnson, 2009) and may enhance pest control in adjacent crops, in some cases up to 200 m from hedgerows (Morandin et al., 2014). If locally-adapted 'insectary plantings' in urban gardens were to have similar effects on natural enemies and pests, biocontrol benefits from a single hedgerow could extend throughout an average-size garden in NYC.

That said, increasing landscape complexity in urban community gardens may not always result in the same outcomes as those documented for rural farms, particularly if fragmentation of the urban landscape prevents natural enemies from colonizing gardens when suitable habitat is provided (Tscharntke et al., 2005). However, the limited research available suggests that habitat management is a viable option and successful practices could be developed for city gardens. We

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documented several natural enemy taxa in NYC gardens that are effective biocontrol agents against problematic insect pests. These included minute pirate bugs and spiders (both generalist predators) as well as ladybird beetle adults and larvae, syrphid fly larvae, and lacewing larvae, all which consume aphids, spider mites, whiteflies, and other soft-bodied insects (Altieri et al., 2010). Though we did not observe high densities of these arthropod predators, their presence in the gardens suggests that providing additional resources through habitat management could augment their populations and biocontrol activity. Indeed, in a parallel study in NYC gardens, we found that increasing floral area significantly increased the density of natural enemies on some crops (Gregory et al., in prep). In urban gardens and lots in Ohio, the abundance of predatory long-legged flies (Dolichopodidae) was positively correlated with bloom abundance, and the abundance of minute pirate bugs was positively correlated with vegetation height (Gardiner et al., 2014). This provides further support for the idea that floral and perennial plantings could contribute to enhanced biological control in urban gardens, though further research (particularly longitudinal study) is needed to evaluate the impacts of habitat management strategies on natural enemy abundance, diversity, predation and parasitism rates, and ultimately crop health in urban gardens.

Incorporating cover crops into vegetable rotations could also enhance conservation biological control in NYC community gardens (in addition to the soil-related benefits discussed above). Over-wintering cover crops such as vetches and clovers supply moisture, physical protection, and food for generalist natural enemies like minute pirate bugs and ladybird beetles, which allows them to establish large populations before key pests of summer vegetables arrive (Clark, 2007: 28). Adding cover crops would also diversify rotations in gardens where the dominance of Solanaceous, Brassica, and Cucurbit crops may worsen pest pressure. Widespread

and repeated planting of crops in these three families may be partially responsible for insect pest problems, as plantings dominated by a single crop or family support larger pest populations and suffer greater yield losses than mixed stands containing lower densities of different crops (Andow, 1991). We found that the most severe insect pest problems in NYC gardens affect the dominant plant families, which supports the hypothesis that resource concentration exacerbates pest damage. Beyond adding cover crops, implementing crop rotations that utilize a diversity of botanical families, and properly rotating these families, could help break pest and disease cycles (Mohler and Johnson, 2009).

Urban gardeners may need to be particularly conscientious about habitat management and rotation planning to support natural enemies and discourage pests, as there are several environmental factors beyond gardeners' control that contribute to urban insect pest populations. First, the increased heat typical of urban environments may contribute directly to the growth of some pest populations (Dale and Frank, 2014). Urban plants also experience stressors that increase their susceptibility to pest colonization. For example, urban plants often suffer water stress due to increased vapor pressure deficit and transpiration (a result of warmer urban temperatures), and/or limited soil water availability in shallow, coarse-textured substrates. Water stress, in turn, may interfere with plant defenses and cause plants to produce sap with high concentrations of amino acids, making them more attractive to sap-feeding insects such as aphids (McIntyre 2000; Cregg and Dix 2001). Combined with low natural enemy densities, these microclimatic factors may play an important role in allowing pests like whiteflies – which are typically considered a greenhouse pest (Klass, 1996; Cole et al., 2009,) – to proliferate in outdoor settings in urban gardens.

Gardening education: Content and program design considerations

Successfully implementing agroecological practices (such as cover cropping, habitat management, and crop rotation) requires ecological knowledge and skills for adapting the practices to local conditions and management goals (Settle, 2000; Shennan, 2008). To support gardeners in developing sustainable practices for urban food production, we suggest that garden educators: 1) incorporate ecological concepts in educational programming, 2) provide follow-up support as gardeners implement, monitor, refine, and share new practices; 3) enhance the accessibility of gardening education.

Our interview findings indicate that most gardeners have general familiarity with ecologically-based practices such as crop rotation and cover cropping, but there are significant gaps in their understanding of ecological concepts that underlie successful implementation of these practices. To address these gaps, garden educators could incorporate ecological knowledge and observations into workshops, educational materials, and technical assistance. Gardeners should understand the functions of a given practice, traits and ecological niches of relevant species (e.g., food crops, cover crops, weeds, arthropod pests and natural enemies, etc.), and ecological processes being managed (Table 1.9). Such knowledge provides a strong basis for making informed choices about agroecological practices to achieve management goals – for example, which cover crops will effectively compete with weeds in a highly fertile garden soil or which floral and woody perennial plantings will provide resources for natural enemies.

In addition to basic ecological knowledge, gardeners also need skills for testing and refining agroecological practices to fit local environmental conditions, a strategy known as 'adaptive management' (Peterson 2005). The experiences of farmers and natural resources managers suggest that experimentation, observation, and reflection in a community of practice may

Table 1.9. Agroecological practices, goals of using them, and key species traits and ecological processes that gardeners should be familiar with to successfully implement and refine agroecological practices.

Agroecological practice	Functions/Goals	Ecological knowledge needed to use the practice successfully	
		Species traits	**Ecological processes**
Cover cropping	• Improve soil quality though organic matter inputs [a] • Improve soil fertility and nutrient cycling through N fixation by legumes, and nutrient retention by non-legumes [b] • Suppress weeds [c] • Provide resources for arthropod pollinators and natural enemies [d]	• Cover crops: Family groupings, seasonal niches, biomass production, N-fixation ability (legumes), competitiveness (germination and growth rates, allelopathic chemicals produced) • Weeds: Life cycles (especially when seed is produced), seasonal niches	• Primary productivity • Nutrient assimilation • Legume nitrogen fixation • Decomposition and nutrient mineralization • Competition (cover crops vs. weeds)
Habitat management (for arthropod natural enemies)	• Reduce herbivorous pest populations and crop damage through conservation biological control [e]	• Arthropod pests: Life cycles, resources requirements, and existing natural enemies (predators and parasitoids) • Arthropod natural enemies: Life cycles, resource requirements (alternative food, shelter, over-wintering), dispersal ranges • Noncrop plants for providing natural enemy habitat: phenology, resources provided,[e] attractiveness to natural enemies (often related to floral area)[f]	• Trophic structure and trophic cascades (indirect interactions across multiple trophic levels; e.g., augmented predator populations increase plant productivity by suppressing herbivore populations)[g] • Over-wintering • Foraging • Predation and parasitism
Crop rotation	• Prevent build-up of diseases and pests specific to particular crop families [h] • Improve soil fertility and nutrient cycling by planting crops with different nutrient requirements, rooting depths, and N-fixing ability [h] • Enhance weed management by planting crops with varying patterns of resource use, allelopathy, and soil management [c, h]	• Crops: Family groupings, seasonal niches, disease and pest susceptibilities, nutrient requirements • Diseases and insect pests: Life cycles, alternate hosts, nonhost period required to eliminate inoculum or eggs/larvae, dispersal capabilities • Weeds: Life cycles (especially when seed is produced), seasonal niches	• Disease and insect pest survival and reproduction • Nutrient assimilation • Legume nitrogen fixation • Competition (crops vs. weeds)

[a] Snapp et al., 2005. [b] Drinkwater and Snapp, 2007. [c] Liebman and Dyck, 1993 [d] Clark, 2007. [e] Landis et al, 2000. [f] Fiedler and Landis, 2007b. [g] Shennan, 2008. [h] Mohler and Johnson, 2009.

promote learning that enables ecologically-based, adaptive management (Kroma, 2006; Warner, 2007; Braun and Duveskog, 2008; Krasny and Tidball, 2009). To support development of adaptive management skills, educators can engage gardeners in monitoring the outcomes of new practices (for example, natural enemy abundance and pest damage on crops before and after the introduction of habitat management plantings) and reflecting in groups on improvements that might be made in gardening practices.

As garden educators work to enhance their programming with ecological knowledge and adaptive management skills, it is important to ensure that such programming is accessible to a broad range of community gardeners. In our interviews, gardeners expressed a strong preference for workshops as the best way to obtain new gardening information, but reported talking with other gardeners and consulting website and print materials more frequently. The gap between gardeners' preferred method for obtaining information (workshops) and the information sources used most frequently (other gardeners, websites, and print materials) likely reflects the additional time and travel commitment associated with attending workshops. Numerous agencies throughout New York City offer workshops on gardening topics, from growing techniques to food preservation to garden organization and leadership.[4] Thus, scarcity of workshops is not likely a problem. Future gardening education efforts might focus on tailoring workshops to the interests of specific gardening groups, enhancing workshop accessibility in terms of scheduling and geographic locations, and providing follow-up support to assist gardeners in implementing new, knowledge-intensive management practices.

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[4] Organizations offering gardening workshops in NYC include: Bronx Green-Up/New York Botanical Garden (http://www.nybg.org/green_up/), Brooklyn Botanic Garden (http://www.bbg.org/greenbridge), East New York Farms! (http://eastnewyorkfarms.org/), Green Guerillas (http://www.greenguerillas.org/index.php), GreenThumb (http://www.greenthumbnyc.org/), GrowNYC (http://www.grownyc.org/), Just Food's City Farms Workshop Series (http://justfood.org/city-farms/community-workshop-series) and Farm School NYC (http://justfood.org/farmschoolnyc).

Given the diversity of languages and cultures in NYC gardens, educators should also strive to provide resources in appropriate languages and develop culturally sensitive programs. While the diversity of languages in NYC community gardens indicates rich opportunities for cross-cultural learning, it likely presents a challenge for organization, communication, and education in gardens. Several authors have cited language and cultural barriers (e.g., lack of seeds and information on ethnic specialty crops) as challenges for gardening education in urban areas (Baker, 2004; Saldivar-Tanaka and Krasny, 2004). Our results indicate strong interest in gardening education materials and support in languages besides English, particularly Spanish.

Conclusions

Despite strong public interest in urban community gardens as sources of healthful produce and sites for environmental stewardship, little research has investigated gardeners' planting and management practices or the ecological characteristics affecting food production in these gardens. Our integrated agroecological and social characterization of NYC community gardens provides insight into challenges for sustainable agricultural production posed by the urban environment and current growing methods, and suggests promising directions for future urban gardening research, education, and practice. Specifically, research and education partnerships are needed to develop urban agriculture practices that build soil quality in raised-beds, promote sustainable nutrient management, and address insect pest damage.

Soil and nutrient management are key challenges for community gardeners. Most NYC gardeners grow crops in raised beds constructed with clean fill and compost. These anthropogenic soils tend to have a sandy texture, low water-holding capacity, high organic matter levels with a large proportion from recent inputs, and excessive nutrient levels (including

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P, K, Mg, and Ca). Cover cropping could improve soil structure and water- and nutrient-holding capacity by adding organic material and promoting aggregation, largely through physical and biological processes associated with root growth and decomposition. Our soil analyses also indicate a need for improved access to soil testing and guidance on appropriate use of soil amendments in order to prevent over-fertilization and associated environmental pollution.

We also found that insect pests in NYC community gardens cause substantial crop damage and loss, and arthropod natural enemies are relatively scarce. While habitat fragmentation and urban environmental conditions likely contribute to high pest and low natural enemy densities in community gardens, land-use practices and crop choices within gardens may exacerbate pest problems. With just a small percentage of garden area devoted to flowers and woody perennials, most gardens may not provide adequate resources for arthropod natural enemies that provide biological control of insect pests. Furthermore, the dominance of just three crop families (Brassicaceae, Cucurbitaceae, and Solanaceae) in NYC gardens may create ideal conditions for insect pests that affect these crops. Research and education efforts to reduce pest damage in urban gardens could focus on habitat management (planting specific floral and woody perennial species to provide resources for predator and parasitoid insects) and diversifying crop rotations.

As researchers and educators partner with urban community gardeners to develop and share ecologically-based practices, thoughtful program design can increase the impact of these efforts. Gardening educators should incorporate ecological knowledge and inquiry-based approaches in their programming to support gardeners in using agroecological management practices and developing adaptive management skills. Enhancing the accessibility of gardening workshops and technical support (in terms of geographic location, scheduling, and languages

offered) is also crucial to ensure that educational programming addresses the needs and taps the knowledge of diverse gardening groups. Working together to understand how garden practices and characteristics impact ecosystem services can inform community garden design and management to achieve food production and environmental quality goals.

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CHAPTER 2

DEVELOPING COVER CROPPING PRACTICES TO IMPROVE SOIL QUALITY,

NUTRIENT CYCLING, AND WEED SUPPRESSION IN URBAN COMMUNITY GARDENS

Megan M. Gregory • Laurie E. Drinkwater

Abstract

Cover cropping may address challenges for sustainable urban food production by providing ecosystem services, including soil quality improvement, weed suppression, and legume nitrogen (N) fixation. To identify promising cover crops for specific management goals and environmental conditions, we conducted field experiments in 17 community gardens in Brooklyn, NY, USA over two field seasons. We collected data on soil properties, light availability, and cover crop performance in research plots planted to eight different cover crops: three winter-kill (field peas, oats, and oats/field peas) and five over-wintering (crimson clover, hairy vetch, wheat or rye, rye/crimson clover, and rye/hairy vetch). Soils generally had sandy textures, low water-holding capacity, high soil organic matter (SOM) content with a large proportion from recent inputs, and excessive nutrient contents. Younger gardens had greater SOM, nutrient, and sand contents and lower C:N ratios compared to older, well-established gardens. Particulate organic matter accounted for an unusually large proportion of SOM compared to field soils as a result of compost additions. Compared to winter-kill cover crops, over-wintering cover crops had greater biomass, weed suppression, legume % NDFA (N derived from the atmosphere), and N fixed. Rye and rye/legume bicultures, with average biomasses over

10,000 kg/ha, were most productive. All over-wintering cover crops, including legume monocultures, provided excellent weed suppression. On average, hairy vetch and crimson clover monocultures and rye/hairy vetch mixtures fixed 190 kg N/ha or more, enough to supply the N needs of heavy-feeding vegetable crops. Rye/hairy vetch mixtures showed evidence of complementary and facilitative interactions, with enhanced vetch and overall productivity compared to component monocultures. Surprisingly, compared to vetch monocultures, planting vetch in mixture with rye nearly doubled average legume soil N uptake (possibly due to priming of SOM decomposition by rye root exudates) and decreased average % NDFA, from 92% in vetch monocultures to 79% in rye/vetch mixtures. In rye/crimson clover and oat/pea mixtures, competition from grasses suppressed legume biomass and severely reduced total N fixed relative to legume monocultures. Light availability was positively correlated with total biomass of field peas, oat/pea mixtures, and rye/vetch mixtures, while other species showed no apparent sensitivity to light availability. High soil fertility decreased % NDFA in field pea monocultures, but not in crimson clover or hairy vetch monocultures, which maintained high % NDFA (averages of 82% and 92%, respectively) across a range of soil N contents. Greater soil fertility and N availability increased fraction legume biomass in oat/pea mixtures and decreased it in rye/crimson clover mixtures. Gardeners' visual estimates of soil cover, fraction legume biomass in mixtures, and weed cover successfully identified differences between cover crop treatments and corresponded well with quantitative sampling data in most cases. To realize the potential benefits of cover cropping in urban gardens, garden educators should: 1) develop gardeners' knowledge of cover crop species' ecology, 2) help gardeners design vegetable rotations that include cover crops, and 3) facilitate access to tools and/or small machinery for cutting down over-wintering cover crops. Such support can help gardeners implement and refine cover

cropping practices to achieve goals for vegetable production and environmental stewardship.

Key Words

community gardens, cover crops, crimson clover, crop rotation planning, ecosystem services, gardening education, field peas, hairy vetch, legume nitrogen fixation, ^{15}N natural abundance method, oats, participatory research, residue management, rye, soil fertility, soil quality, urban agriculture, weed suppression

Introduction

Urban gardens: Benefits and challenges for sustainable food systems and cities

Public interest and participation in urban food gardening in North America has grown in recent years, along with social movements for just and sustainable food systems (Levkoe, 2006; Teig et al., 2009; Draper and Freedman, 2010; Drake and Lawson, 2015). City gardens provide opportunities for residents to grow healthy produce that may be unavailable or unaffordable in urban neighborhoods. These gardens may produce nutritionally and economically meaningful amounts of food (Blair et al., 1991; Baker, 2002; Vitiello and Nairn, 2009; Gittleman et al., 2012; Algert et al., 2014; Conk and Porter, 2016) and improve nutrition for gardeners and their families (Alaimo et al., 2008; Litt et al., 2011). Gardeners also seek to practice environmental stewardship by tending green spaces in cities (Armstrong, 2000; Ohmer et al., 2009; Draper and Freedman, 2010).

Despite strong public interest in urban food production, little research has explored agricultural production challenges and ecological processes in city gardens (Guitart et al., 2012; Pfeiffer et al., 2014). Agricultural research in these settings can help gardeners develop

sustainable management practices tailored to urban environments and production challenges, which differ from those of rural locations. Compared to rural farms, city gardens experience increased shading from buildings and elevated temperatures, moisture stress, and concentrations of air pollutants (Pfeiffer et al., 2014; Wagstaff and Wortman, 2015; Gregory et al., 2016). Since urban gardeners often rely on raised beds to create a suitable growing medium on compacted lots and minimize exposure to soil contaminants, they also face distinct challenges for soil and nutrient management (Clark et al., 2008; Witzling et al., 2010; Pfeiffer et al., 2014; Mitchell et al., 2014). Due to the sandy clean fill materials used to construct them, raised-bed soils may have poor structure, coarse textures, and low water-holding capacity, which can compromise crop health and production (Pfeiffer et al., 2014; Cameira et al., 2014; Gregory et al., 2016). Furthermore, urban growers often rely on external nutrient sources such as fertilizer or compost. Studies have documented excessive nutrient contents in urban gardens, suggesting that typical rates of compost and fertilizer application may cause nutrient imbalances and pollute surface and groundwater (Witzling et al., 2010; Dewaelheyns et al., 2013; Cameira et al., 2014; Gregory et al., 2016). Finally, gardeners in New York City (NYC) report intense weed pressure, perhaps due to weed seeds from imported soil and compost and/or blown in from vacant lots (Gregory et al., 2016).

Cover cropping: An agroecological practice for urban gardens
Cover cropping is an agroecological practice that may address some challenges for sustainable urban food production. This practice involves sowing close-growing plants in rotation with food crops to cover bare ground and provide other benefits, such as legume nitrogen (N) fixation and weed suppression. Before planting the next food crop, cover crops are either cut down and left

as mulch on the soil surface, or incorporated into the soil. Two commonly used families of cover crops are grasses (Poaceae) and legumes (Fabaceae) (Treadwell et al., 2010; CTIC / SARE, 2014).

Ecosystem services of cover crops

Cover cropping may provide ecosystem services that enhance food production and reduce the environmental impacts of agriculture (Schipanski et al., 2014; Finney et al., 2016). Cover crops increase soil organic matter (SOM) contents by adding plant residues and enhancing soil aggregation and physical protection of SOM through root growth and decomposition (Puget and Drinkwater, 2001; von Luetzow et al., 2006; Po et al., 2009; McDaniel et al., 2014). SOM, in turn, improves soil structure and water- and nutrient-holding capacity (Wander, 2004; Snapp et al., 2005). Legume cover crops add 'new' N to agricultural systems through N fixation, which occurs when N-fixing bacteria in legume roots convert atmospheric N to a plant-available form. As legume residues decompose, they supply N that supports food crop production (Drinkwater et al., 2008). Over-wintering non-legumes improve nutrient retention by taking up excess nutrients at the end of the growing season, thus reducing nutrient leaching and pollution of aquatic ecosystems (Tonitto et al., 2006; Gardner and Drinkwater, 2009; Finney et al., 2016).

Weed suppression is another benefit of cover cropping. Growing cover crops may suppress weed germination and growth through competition (e.g., for space, light, nutrients, and water) and alleleopathy (Snapp et al., 2005; Khanh et al., 2005; Weston, 2005; Finney et al., 2016). After termination, cover crop residue left on the soil surface may provide a physical barrier to weed emergence, block light, and reduce spring soil temperatures and temperature fluctuations (required by some weed seeds to break dormancy) (Liebman and Dyck, 1993;

Teasdale and Mohler, 1993; Mohler and Teasdale, 1993; Creamer et al., 1996; Blum et al., 1997; Williams II et al., 1998; Radicetti et al., 2013).

Perhaps as a result of these ecosystem services, vegetable crops planted into cover crop mulches may yield more than in no-cover-crop systems (Abdul-Baki and Teasdale, 1997; Abdul-Baki et al., 2002; Mennan et al., 2009; Radicetti et al., 2013; Campiglia et al., 2014b), or produce equivalent yields with less external inputs (Creamer et al., 1996; Sainju et al., 2002; Campiglia et al., 2014b). Given the many benefits of well-chosen cover crops, integrating cover crops in urban gardeners' vegetable rotations may mitigate challenges such as poor soil quality, nutrient imbalances resulting from over-reliance on compost, and weed pressure.

Species composition and environmental effects on cover crop performance
Cover crop performance and ecosystem service provision varies widely with species composition and environmental conditions. In general, grasses establish quickly, produce large biomass that contributes to SOM, take up and recycle inorganic N, and suppress weeds effectively (Shipley et al., 1992; Blum et al., 1997; Snapp et al., 2005; Tonitto et al., 2006; Treadwell et al., 2010; Finney et al., 2016). Legumes tend to establish more slowly and produce modest biomass, but contribute fixed N to agricultural systems, improve soil aggregation and tilth, increase SOM, and may enhance yields of subsequent vegetable or grain crops (Haynes and Beare, 1997; Puget and Drinkwater, 2001; Abdul-Baki et al., 2002; Snapp et al., 2005; Kong et al., 2005; Sainju et al., 2005; Finney et al., 2016).

Certain mixtures of grasses and legumes combine the benefits of both types of cover crops. Research in natural and agricultural ecosystems suggests that functionally diverse mixtures of plant species may use resources more efficiently and provide a broader range of

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ecosystem services when compared with monocultures. In grasslands, plant species and functional diversity increase ground cover, above- and below-ground biomass production, N uptake, and SOM accrual. Relative to monocultures, diverse mixtures also show lower available soil nitrate and transmitted light at the soil surface, indicating more efficient resource use (Tilman et al., 2001; Spehn et al., 2005; Fornara and Tilman, 2008). Similarly, in agricultural systems, certain cover crop mixtures achieve high biomass, effective weed suppression, efficient N retention by nonlegumes, contributions of fixed N from legumes, and ideal rates of N mineralization from cover crop residues to supply the needs of subsequent food crops (Creamer et al., 1996; Ranells and Wagger, 1997; Teasdale and Abdul-Baki, 1998; Sainju et al., 2005; Parr et al., 2011, 2014; Finney et al., 2016). Such positive effects of plant diversity on ecosystem services likely result from complementary resource use and facilitative interactions in mixtures (Spehn et al., 2005; Cardinale et al., 2007).

However, not all plant species mixtures provide enhanced ecosystem services relative to monocultures. In grass/legume cover crop mixtures, legume biomass and total N fixed may be severely suppressed, particularly where competitive grass species (e.g., rye, sorghum-sudangrass) or low-growing legumes (e.g., clovers) are used, and/or where high soil N fertility stimulates large biomass production by the grass (Karpenstein-Machan and Stuelpnagel, 2000; Hauggaard-Nielsen et al., 2001; Tosti et al., 2010; Finney et al., 2016). Low legume percentage, in turn, can result in a high C:N ratio, N immobilization, and reduced yields in subsequent crops (Finney et al., 2016).

In addition to species composition, environmental conditions such as soil properties and light availability also influence cover crop performance. For example, sandier soils support greater legume biomass production and N fixation than clay soils, and available soil N may

reduce the efficiency of legume N fixation (Schipanski et al., 2010). Soil fertility has a strong

effect on biomass composition of grass/legume mixtures, with high fertility and N availability

favoring grass production at the expense of legume biomass, N fixation, and N supply to

subsequent crops (Schipanski and Drinkwater, 2012; Finney et al., 2016). Such variation in

cover crop performance with soil conditions has important implications for cover crop

recommendations to urban gardeners. Raised-bed urban garden soils differ from natural field

soils where the majority of cover crop research has been conducted. Furthermore, SOM and

nutrient contents in NYC urban garden soils vary widely within and across gardens (Gregory et

al., 2016). To our knowledge, no published studies have examined the implications of variation

in soil properties for cover crop performance in raised-bed urban soils. Furthermore, we are not

aware of studies on how light availability impacts cover crop performance – an important

knowledge gap for cover crop selection in urban gardens, many of which are located between

buildings. To make well-informed cover crop recommendations for city gardeners, we need

information on cover crop performance in urban contexts.

Project overview and research questions

We worked with gardeners in Brooklyn, NY to study cover crop performance across a range of

soil and light environments in urban community gardens. Our goal was to identify cover crops

that are suitable for the crop rotations, environmental conditions, and management practices in

urban gardens. We planted and monitored eight cover crop combinations over two seasons,

focusing on annual winter-kill and over-wintering cover crops[5] planted near the end of the

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[5] *Winter-kill cover crops* are planted in late summer, grow during the fall, and die over the winter. These cover crops are suitable for preceding early spring vegetables (e.g., Brassica crops). *Over-wintering cover crops* are established in fall, survive the winter, and resume growth in spring before being cut down at flowering. Since these cover crops grow through early spring, they are best followed by warm-season crops (e.g., tomatoes and Cucurbits).

growing season. Using data on environmental conditions, cover crop performance, and

gardeners' experiences monitoring and managing the cover crops, we addressed the following

questions:

1) How do cover crop species composition and seasonal niche affect cover crop

   performance in urban gardens, specifically: biomass production, legume N fixation and

   weed suppression?

2) How does variation in soil properties and light availability influence the performance of

   specific cover crop combinations?

3) What field-based observations can gardeners use to monitor and evaluate cover crop

   performance for specific management goals?

4) How do gardeners adjust their management practices to incorporate cover crops in their

   rotations? Are these changes seen as feasible and worthwhile? Why or why not?

Methods

Participatory research context and study sites

We worked with two participatory research groups involving 60 gardeners to define priority

management goals for cover cropping, select species to test, and plant and monitor cover crops

over two field seasons (2011-2012, hereafter 'Year 1,' and 2012-2013, 'Year 2'). Table 2.1

outlines research and education activities during each field season. We established cover crop

research plots in 17 community and backyard gardens in Brooklyn, NY over the two study-years.

The humid, temperate climate has a mean annual precipitation of 1136 mm (44.7 in) and mean

annual minimum and maximum temperatures of 9°C (48°F) and 17°C (63°F), respectively (U.S.

National Climatic Data Center). Gardeners grow crops in raised beds constructed with mixes of

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Table 2.1. Timing of field research activities in Brooklyn gardens during the 2011-12 and 2012-13 field seasons.

Cover Crop Research and Education Activities	Year 1: 2011-12	Year 2: 2012-13
Research Design • Define priority management goals for cover cropping (soil quality and fertility, weed suppression). • Choose cover crop seasonal niches and species to test.	July-August 2011	Late June 2011
Rotation planning workshop	n/a	17 July 2012
Cover crop selection & plot marking	August 2011	July-August 2012
Characterizing plot background conditions: Fieldwork • Soil sampling • Take hemispheric photos to measure light availability	August 2011	August 2012
Plant field pea, oat, and oat/pea plots (winter-kill cover crops)	n/a	21-28 August 2012
Plant crimson clover, rye,* and rye*/clover plots	30 August – 2 September 2011	6-15 September 2012
Plant hairy vetch, rye,* and rye*/vetch plots	24 September – 4 October 2011	29 September – 8 October 2012
Winter-kill cover crops: Fall monitoring by gardeners • Record observations of cover crops: soil cover (visual estimate), plant height, estimated mixture composition, legume flowering dates, weed suppression, and legume nodule number and color.	n/a	15-20 October 2012
Winter-kill cover crops: Biomass sampling	n/a	1-12 November 2012
Over-wintering cover crops: Fall monitoring by gardeners	22-29 October 2011	1-5 November 2012
Over-wintering cover crops: Spring monitoring by gardeners	17-30 April 2012	30 April – 6 May 2013
Cover crop management workshop (tools and techniques for mulching over-wintering cover crops)	n/a	23 April 2013
Over-wintering cover crops: Biomass sampling	18-27 April 2012	30 April – 17 May 2013

* The over-wintering grass cover crop was winter wheat in Year 1 and winter rye in Year 2. Rye is listed in the table since we protected newly planted Year 2 plots from seed predation by birds. Therefore, Year 2 plots established most successfully and were used for most analyses presented in this paper.

sandy clean fill, topsoil, and compost. In general, the constructed soils have coarse textures and high SOM and nutrient contents (Chapter 1; Gregory et al., 2016). Only one garden had used cover crops prior to this project. Most research plots had vegetable crops growing in them at the time of cover crop planting; we seeded cover crops between these crops.

Characterizing background environmental conditions

Soil properties

Detailed sampling and analysis methods for most soil tests are presented in Chapter 1 (Gregory et al., 2016). Prior to planting cover crops, we collected soil samples from all research plots in August and September of 2011 and 2012. For all plots (n=266), we measured particle size distribution, pH, available phosphorous (P), potassium (K), calcium (Ca), and magnesium (Mg), and total carbon (C) and N. For a subset of plots (n=36 in 2011 and n=54 in 2012) we also measured bulk density, soil water content at field capacity (g water/g moist soil, expressed as %H_2O), and C and N contents of particulate organic matter (POM; organic matter > 53 μm and usually derived from recent inputs). POM was further separated to distinguish free POM (fPOM, outside soil aggregates and accessible to soil microbes) from occluded POM (oPOM, inside soil aggregates).

We extracted POM fractions using the size and density separation method presented in Marriott and Wander (2006) with slight modifications to accommodate the large quantity of fPOM in these compost-rich soils (Marriott and Wander, 2006b). To obtain fPOM, we dispersed 40-g subsamples of air-dried, sieved soil in sodium polytungstate (1.7 g/cm^3) by shaking on an orbital shaker for 1 hour at 100 rpm. After standing overnight, all fPOM floating on the sodium polytungstate was collected on a 53-μm sieve, rinsed, and dried for 48 hours at 60°C. To obtain

oPOM, we dispersed the remaining heavy fraction in 150 mL of 10% sodium hexametaphosphate. Samples were shaken on a reciprocal shaker for 1 hour at 250 rpm to disperse soil aggregates, then rinsed through 53-μm mesh fabric. We then decanted oPOM onto 53-μm mesh fabric and rinsed the sample before drying for 48 hours at 60°C. We weighed and ground dried fPOM and oPOM fractions and analyzed subsamples for C and N by dry combustion using a LECO 2000 CN Analyzer (LECO Corporation, St. Joseph, MI).

Light availability

To estimate light availability to research plots, we took hemispheric photos (Jonckheere et al., 2004) at ≥ 5 points in each garden. These photos are oriented toward the sky and use a fisheye lens to capture objects that attenuate light (e.g., buildings, trees) in a 180° field of view. We then analyzed the photos with SideLook vers. 1.1 (Nobis and Hunziker, 2005) and Gap Light Analyzer, Version 2.0 (Frazer et al., 1999) to obtain the average total percent transmitted light at each point for the time frame of cover crop growth (for winter-kill cover crops, August 15-November 15; for over-wintering cover crops, a weighted average of September 15-December 1 and March 1 – May 1). All cover crop plots were matched with the nearest hemispheric photo to estimate average percent transmitted light.

Cover crop planting and management

We embedded cover crop research plots in garden beds across 17 gardens. The plant species used and number of plots planted to each are summarized in Table 2.2. Each legume monoculture and grass/legume mixture had a corresponding grass monoculture grown within the same management unit. The grass monocultures served as reference plants for measuring

legume N fixation using the natural abundance method (see below) (Shearer and Kohl, 1986).

Table 2.2. Cover crop treatments planted in Brooklyn gardens, scientific names, seasonal niches, and number of gardens and plots planted in each year of the study.

Cover crop treatment	Scientific name(s)	# gardens/ plots (2011-12)	# gardens/ plots (2012-13)
Winter-kill cover crops			
Oats	*Avena sativa*	n/a	10 / 31
Field peas	*Pisum sativum*	n/a	10 / 21
Oats/peas	*A. sativa / P. sativum*	n/a	9 / 20
Over-wintering cover crops			
Winter rye (2012-13) or Winter wheat (2011-12)	*Secale cereale* *Triticum aestivum*	12 / 53	10 / 70
Crimson clover	*Trifolium incarnatum*	10 / 23	9 / 22
Rye or wheat/crimson clover	*S. cereale / T. incarnatum*	9 / 23	10 / 20
Hairy vetch	*Vicia villosa*	10 / 22	10 / 21
Rye or wheat/hairy vetch	*S. cereale / V. villosa*	10 / 23	10 / 25

We established plots in late summer and fall of each year according to optimum planting dates for each cover crop combination (Table 2.1). After removing weeds and crop residues and cultivating the soil, we hand-broadcast seed into 1.5 m x 1.2 m (5 ft x 4 ft) plots. Legume and grass monocultures received ½ cup of seed each, while grass/legume mixtures were planted with ¼ cup of legume seed plus ¼ cup of grass seed. Legumes were inoculated with N-Dure species specific inoculant prior to planting. Due to seed predation by birds on research plots during our first year of research, in Year 2 we covered newly planted seed with row cover until the plants were several inches tall. Gardeners did not weed or apply amendments to cover crop plots during the experiment.

We also designated control plots for each cover crop plot -- constructed from the same

soil – to serve as baselines for weed assessments in cover crop research plots. Since background

weed pressure varies depending on the soil and compost used to construct raised beds, this

provided a mechanism for comparing across gardens and beds. In control areas, gardeners

maintained vegetable crops and removed weeds at the time of cover crop planting, but did not

plant cover crops. Due to space limitations, many control plots contained dense plantings of

vegetables, and likely underestimate the weed growth that would have occurred in less densely

planted areas.

Cover crop monitoring and sampling

To assess cover crop performance, we used a combination of quantitative sampling and

systematic, field-based observations by gardeners.

Quantitative sampling

We measured soil cover in each legume and grass/legume plot using grid sampling at three, six,

and nine weeks after planting. At or near cover crop maturity (indicated by legume flowering),

we sampled 0.125 m^2 of aboveground biomass from the center of all cover crop and control plots

(Table 2.1). We separated biomass samples into legume, grass, and weed components, dried

each component at 60 °C and weighed them to obtain dry biomass of cover crops and weeds.

To calculate weed suppression, we compared dry weed biomass in each cover crop plot

with that of the corresponding control plot. Weed suppression for each cover crop plot was

calculated as the percent reduction in weed biomass relative to its control plot:

$$\% \text{ Weed suppression} = \frac{(\text{Control plot weed biomass} - \text{Cover crop plot weed biomass})}{\text{Control plot weed biomass}} \times 100\%$$

We estimated legume N fixation in each legume monoculture and grass/legume mixture plot using the natural abundance method (Shearer and Kohl, 1986). This method relies on the fact that atmospheric nitrogen (N_2) has a lower ratio of ^{15}N:^{14}N than soil-derived nitrogen due to biological processes in the soil that discriminate against the heavier ^{15}N isotope and favor the loss of ^{14}N to the atmosphere via denitrification and volatilization. While grasses grown in monoculture derive all of their N from soil pools, legume N is a mixture of N taken up from soil pools and N derived from the atmosphere (NDFA) through nitrogen fixation. We used grass monocultures as reference plants to estimate the $\delta^{15}N$ (per mil enrichment in ^{15}N compared to atmospheric N) of plants relying solely on soil N in each research plot. Winter wheat and winter rye served as reference plants for over-wintering legumes in Year 1 and Year 2, respectively, while oats served as reference plants for field peas.

Legume samples from monocultures and mixtures, and their corresponding grass reference samples, were finely ground using a hammer mill followed by roller-grinding. Samples were analyzed for % N and $\delta^{15}N$ using a Continuous Flow Isotope Ratio Mass Spectrometer (UC Davis Stable Isotope Facility). We then calculated the % NDFA in legume biomass using a mixing model:

$$\% \text{ NDFA} = \frac{\delta^{15}N_{\text{grass}} - \delta^{15}N_{\text{legume}}}{\delta^{15}N_{\text{grass}} - B} * 100\%$$

where:

- $\delta^{15}N$ is the per mil enrichment of a plant sample in ^{15}N compared to atmospheric N,

- B is the $\delta^{15}N$ of the legume plant when it derives all its N from fixation, and represents the isotopic fractionation that occurs during N fixation and assimilation into aboveground plant tissue for each legume species.

For each legume species, we relied on *B* values from the literature as *approximate* representations of the $\delta^{15}N$ when the legume derives all its N from the atmosphere. Legume *B*-values are influenced by the rhizobial strains inhabiting legume roots, which vary across soils (Parr et al., 2011). This posed a challenge for our study, as soils showed high variability within beds, across beds, and across gardens (Gregory et al., 2016). Since our cover crop plots were located in hundreds of distinct soils, it would not have been feasible to determine *B*-values using rhizobial strains from every plot. Therefore, for field pea and crimson clover, we used *B*-values determined in previous greenhouse studies in NY, while for hairy vetch we used an average of *B*-values determined for vetch in various studies. The *B*-values used were: field pea, -1.55 ‰ (Schipanski and Drinkwater, 2012); crimson clover, -0.74 ‰ (van Zyl, 2009); and hairy vetch, -0.79‰ (Unkovich et al., 2008). After determining the % NDFA for each plot, we then calculated total N fixed as follows:

N fixed (kg/ha) = Legume biomass (kg/ha) * Biomass N concentration * % NDFA

Field-based observations by gardeners

We also engaged gardeners in observing cover crop performance using checklists of indicators linked to improved soil quality and fertility and weed suppression. The purpose of this was twofold. First, we hoped that monitoring cover crop performance would develop gardeners' knowledge and skills for refining their cover cropping practices. Second, we compared gardeners' assessments of the cover crops with our quantitative measures to identify useful field-based indicators of cover crop performance. Gardener monitoring checklists included indicators in four categories: cover crop growth, weed suppression, N fixation, and legume flowering dates

(Table 2.3). We facilitated monitoring workshops to assist gardeners in observing their cover

crops and recording data. Field pea and crimson clover plots, and their corresponding

grass/legume mixtures, were monitored in the fall two months after planting, while hairy vetch

plots were monitored one month after planting. Gardeners observed and recorded data on over-

wintering cover crop plots again in the spring just before sampling (late April 2012 and early

May 2013).

Gardener perspectives on cover crop management and impacts

To understand gardeners' perspectives on cover crop management and impacts, we conducted

brief interviews in mid-summer 2012 and mid-summer 2013. The survey included questions on

cover crop management in preparation for planting vegetables and perceived impacts of the

cover crops. We first noted the date gardeners cut down the cover crops and the tools and

methods used. We then asked open-ended questions about what worked well and what gardeners

would like to improve or do differently in the future. Our conversations focused on methods to

prepare cover-cropped plots for planting vegetables, but gardeners also commented on their

overall experience incorporating cover crops into their gardens.

In the section on perceived impacts of the cover crops, we asked gardeners if they had

observed lasting differences between cover-cropped plots and control plots (or past years) in

terms of weed suppression and soil tilth and moisture. In Year 1, without prompting, more than

one-third of gardeners also reported improved growth of vegetable crops planted after the cover

crops with less fertilizer than in past years (and in many cases, with no additional amendments).

As a result, in Year 2 we also asked all gardeners about possible improvements in soil fertility

due to the cover crops, as reflected in vegetable crop performance relative to past years.

Table 2.3. Field-based indicators of cover crop performance observed and recorded by gardeners for each plot in fall (two months after planting for field pea, oat/pea, crimson clover, and rye/crimson clover plots; one month after planting for hairy vetch and rye/hairy vetch plots), and spring (over-wintering plots only).

Indicator	Method(s)
Cover crop growth	
Percent cover	• Visual estimate, with percent cover charts for reference
Plant height	• Measurements at two points in each plot (legume and grass heights recorded separately in mixtures)
Mixture composition	• Visual estimate of % grass and % legume, with percent cover charts for reference
Weed suppression	
Percent weed cover	• Visual estimate, with percent cover charts for reference
Most common weeds	• Identification, with field guides and assistance of horticulturalist
Weed suppression	• Comparison of weed pressure in cover crop plot with that in the control plot (less, more or same amount of weeds)
	• Rating of degree of satisfaction with weed control (not satisfied, somewhat satisfied, very satisfied)
Nitrogen fixation	
Number of nodules	• Average of number of nodules on two legume plants
Inner color of nodules [a]	• Color rating upon cutting open 3 nodules on each of two plants: 0 = All nodules white or green (no N fixation), 1 = Some pink nodules, 2 = Mostly or all pink nodules
Legume flowering [b]	
Date of first flowering	• Gardener estimate
Cover crop maturity	• Estimated % of legume plants flowering (0-25%, 26-50%, 51-75%, 76-100%)

[a] A pink or red color inside the nodules signifies that the *Rhizobia* bacteria are actively fixing nitrogen. The color comes from the activity of an enzyme, leghemoglobin (jointly synthesized by the legume and the bacteria). This enzyme lowers oxygen concentrations in parts of the nodule where nitrogen fixation occurs, protecting the N fixation enzymes.

[b] Flowering is an important indication of maximum biomass and, for legumes, nitrogen fixation. To maximize biomass and nitrogen contributions to the soil, gardeners should wait until more than 50% of legume plants are flowering before terminating the cover crop (Clark, 2007).

Data analysis

<u>Soil properties</u>

We used principal components analysis (PCA) on the correlation matrix of soil variables to identify independent, composite variables representing major sources of variability. Data from soils collected in 2011 and 2012 were analyzed together. Prior to conducting PCA, we assessed all soil variables for normality. Percent sand, clay and pH had acceptable distributions without transformation. We log-transformed N, C:N ratio, P, K, Mg, and Ca to fit normal distributions. We then removed 12 plots with extreme outlying values of one or more soil variables. We retained principal components with eigenvalues greater than 1 and accounting for more than 10% of the variation in the soils dataset. Variables with eigenvectors (loadings) of greater than 0.30 on a principal component were considered significant contributors to that component.

<u>Species composition effects on cover crop performance</u>

Due to differences in cover crop establishment between Year 1 and Year 2, we analyzed data for each year separately. We used an analysis of variance to compare average cover crop performance measures across treatments. Since residuals were not normally distributed, we used Steel-Dwass nonparametric comparisons to identify significant differences between treatments.

To better understand variability in the relative performance of legumes, grasses, and grass/legume mixtures, we graphed cover crop performance measures for Year 2 plots in which a legume monoculture, grass monoculture, and grass/legume mixture were grown in the same management unit. This allowed for comparison of different species compositions grown under similar soil and light conditions across a range of soil N contents. We also used this subset of plots to calculate the Land Equivalent Ratio (LER) for each mixture and the partial LER (pLER)

for component species. The LER is the relative amount of land that would need to be planted in

monocultures to produce equivalent yields to those achieved in a mixture (Willey and Osiru,

1972), and has been used to determine if cover crop mixtures confer benefits in terms of biomass

or N accumulation compared to monocultures (Wortman et al., 2012; Schipanski and

Drinkwater, 2012; Smith et al., 2014; Hayden et al., 2014). For our grass/legume mixtures, we

calculated partial and total LERs as follows:

pLER (legume) = legume dry biomass in mixture / legume dry biomass in monoculture

pLER (grass) = grass dry biomass in mixture/ grass dry biomass in monoculture

LER = pLER (legume) + pLER (grass)

For each mixture, we calculated average partial and total LERs and used Wilcoxon signed rank

tests to determine if pLERs were significantly different from 0.5 and total LERs were

significantly different from 1. Partial LERs significantly greater than the species' sown

proportion (here, 0.5) and total LERs greater than 1 suggest possible complementary and/or

facilitative interspecific interactions, while partial LERs less than 0.5 and total LERs less than 1

suggest antagonistic interactions between species (Vandermeer, 1989; Wortman et al., 2012;

Smith et al., 2014).

Environmental effects on cover crop performance

Due to the variable (and generally poor) establishment of the cover crops in Year 1 as a result of

seed predation by birds, we focused on Year 2 data to analyze the effects of environmental

variability on cover crop performance. Since plots with the highest soil N contents were found

only in gardens with high light, we analyzed two subsets of Year 2 data to separate effects of soil

properties and light (see 'Results: Environmental and management conditions' for details of the

two subsets). We conducted PCAs on soil properties for each subset plots to summarize major sources of variation with several independent, composite variables (principal components), which we then used to explore how soil properties impacted cover crop performance. For each subset of data, we then calculated Pearson correlations between environmental variables and cover crop performance measures for each treatment to identify significant effects. Since analysis of treatment means revealed unexpected patterns in N fixation in vetch monocultures and rye/vetch mixtures, we explored these trends further using 'pairs' of vetch and rye/vetch plots grown in the same management unit or within the same garden and in similar soil and light conditions. For these plots, we analyzed correlations between environmental variables and *differences* in vetch performance in corresponding monocultures and mixtures.

Gardener monitoring and perspectives on cover crop management

We compared the results of gardener monitoring with those obtained through quantitative sampling at the level of overall conclusions and plot-level measurements. For categorical variables on the monitoring checklist (percent cover classes and nodule color ratings) we constructed boxplots of quantitative measurements for the plots assigned to each class by gardeners and examined the degree of agreement. For continuous variables (visual estimates of percent legume in mixtures and weed cover) we ran simple regressions of gardeners' estimates vs. quantitative measurements.

To analyze gardeners' perspectives on cover crop management, we coded gardeners' responses to interview questions to identify common management approaches, challenges, and innovations in preparing plots for vegetables. Our extended, informal experiences talking with gardeners during workshops also informed our interpretation of themes in cover crop

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management challenges and solutions. Finally, for each category of possible cover crop impacts (weed suppression, soil tilth, soil moisture, and nutrient supply to crops), we calculated percentage of gardeners who reported positive impacts of the cover crop compared to bare fallow plots or previous years, with separate analyses by year and seasonal niche (over-wintering vs. winter-kill).

Results

Environmental and management conditions

The weather varied between Year 1 and Year 2, but was generally favorable for growth of over-wintering cover crops (Fig. 2.1). In Year 1, temperatures were warmer than average during most of the cover crop growth period, while spring precipitation was below average. In Year 2, winter-kill cover crops were affected by Hurricane Sandy and an unseasonable winter storm near the end of their growth period. As such, biomass and N fixation measurements for winter-kill species may not represent their full potential under ideal fall growing conditions. The over-wintering cover crops did not suffer substantial damage from the 2012 storms, as they were recently planted and therefore close to the ground during the severe weather. Overall, Year 2 had dry weather in fall and spring and cooler-than-average spring temperatures, which delayed maturity and sampling of over-wintering cover crops (Table 2.1).
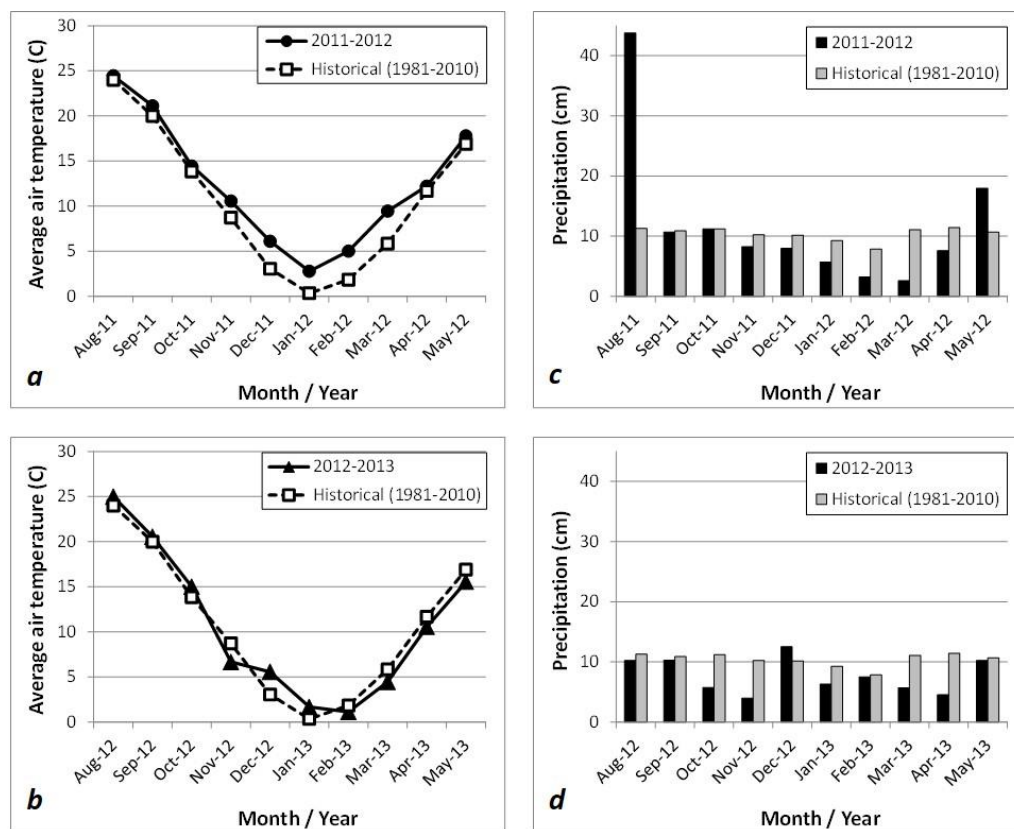
Fig. 2.1. Average monthly (a, b) air temperatures and (c, d) total precipitation for cover crop growth periods in (a, c) 2011-12 and (b, d) 2012-13, compared with 30-year historical averages for Brooklyn, NY.

Table 2.4 presents summary statistics for soil properties and light availability in research plots. For averages of soil properties by garden, see Chapter 1 (Gregory et al., 2016). Raised-bed soils in Brooklyn gardens had consistently coarse textures and slightly alkaline pH, reflecting the sandy clean fill used to build raised beds and concrete-rich urban environment. Soil properties that respond strongly to management, including SOM and nutrient contents, varied widely within and across gardens. For example, average soil N ranged from 0.5 – 7.1 g N/ kg soil across gardens, more than 14-fold variation. Quantities of P, Mg, and Ca in all plots exceeded recommended amounts (NJAES, 2014). Most plots also had optimum to excessive K, though 15% had suboptimal K (data not shown).

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Table 2.4. Summary statistics for soil properties and light availability measured in cover crop research plots in 17 Brooklyn gardens in the Fall of 2011 and 2012. Data on texture (% sand, % clay), pH, P, K, Mg, Ca, Total C, Total N, and light availability are based on 157 beds containing 266 research plots. Data on POM-C and –N, bulk density and water content at field capacity are based on triplicate samples from a subset of 57 beds containing 89 research plots across six gardens. For averages of soil properties by garden, see Chapter 1 (Gregory et al., 2016). CV= coefficient of variation.

Environmental Variable	Mean	Range (Garden Avgs)	Overall CV	Avg within-garden CV
Soil texture				
Sand (%)	69	62 - 78	9%	5%
Clay (%)	10	5 - 14	38%	22%
Soil chemistry and nutrients				
pH	7.2	6.3 - 7.5	3%	2%
P (mg/kg)	237	59 - 471	44%	27%
K (mg/kg)	199	63 - 498	74%	53%
Mg (mg/kg)	327	109 - 548	37%	22%
Ca (mg/kg)	3266	930 - 4120	21%	14%
Soil organic matter: quantity and composition				
C (g/kg)	58.2	17.6 - 136.2	60%	29%
N (g/kg)	3.3	0.5 - 7.1	75%	37%
C:N	21.3	15.4 - 42.7	43%	15%
POM-C (g/kg)	38.5	16.5 - 72.1	92%	65%
POM-N (g/kg)	2.3	0.8 - 4.8	99%	68%
Soil structure and water-holding capacity				
Bulk density (g/cm^3)	1.04	0.87 - 1.37	27%	21%
Field capacity (g H_2O/g moist soil)	25%	19% - 27%	27%	24%
Light availability				
% Trans Total	67%	20% - 96%	38%	18%

The quantity and distribution of soil N and C in POM fractions distinguished these urban garden soils from agricultural field soils (Fig. 2.2). Since N and C were strongly correlated in the combined 2011 and 2012 dataset (r=0.95), we present data on soil N both to represent the distribution of SOM and to characterize potential N availability to plants. Compared to field soils, Brooklyn garden soils had similar amounts of N in stabilized SOM, but 30-60 times more N in fPOM and a greater proportion of total N in fPOM (on average, 48%). In all gardens, fPOM-N exceeded oPOM-N, with oPOM-N : fPOM-N ratios of 0.05 – 0.80 and an average of 0.13. In contrast, field soils typically have less than 20% of total N in POM and just 2-3% of total N in fPOM. Furthermore, field soils tend to have more oPOM-N than fPOM-N, with ratios near 5 (Wander and Bidart, 2000; Schipanski et al., 2010).
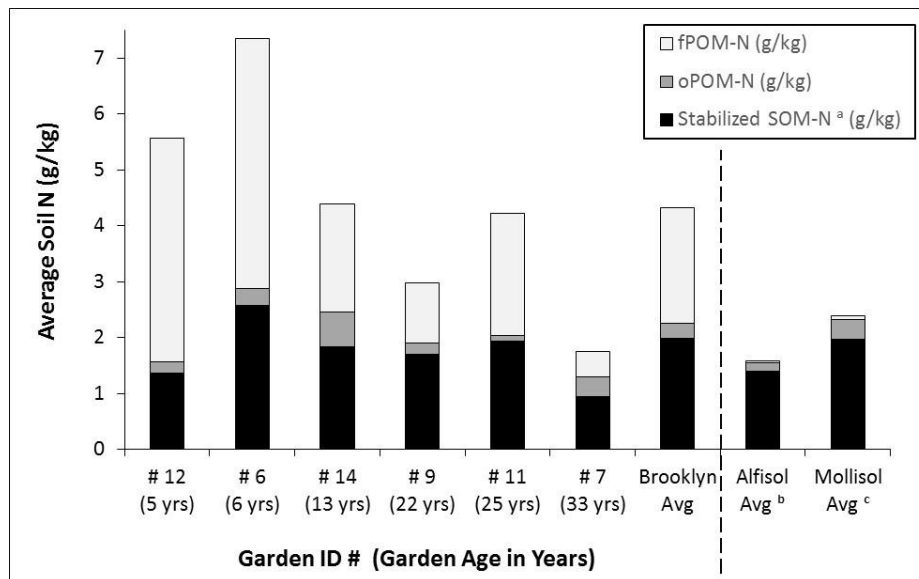
Fig. 2.2. Average quantity and location of soil N in six Brooklyn gardens, compared to Alfisol and Mollisol field soils. Garden ID numbers correspond with those in Chapter 1 (Gregory et al., 2016). Brooklyn gardens data are based on 57 beds containing 89 research plots sampled in Fall 2011 and Fall 2012. SOM= Soil organic matter.

[a] The pool we have labelled 'stabilized SOM-N' is dominated by N in stable organic matter pools, with small contributions of labile pools (e.g., dissolved organic N and microbial biomass N).

[b] Based on data from Schipanski and Drinkwater, 2010 (average of 8 organically managed farm fields in upstate NY, USA).

[c] Based on data from Wander and Bidart, 2000 (average of three field sites in IL, USA).

SOM distribution across fPOM, oPOM, and stable SOM fractions in Brooklyn gardens reflected garden age and management practices. Younger gardens had greater quantities of fPOM-N and lower oPOM-N : fPOM-N ratios compared to older gardens (Fig. 2.2). The main exception to this trend, Garden #11, was revitalized (after a period of disuse) the year before our research began. Addition of new soil and compost on top of old material may account for this garden's relatively large average quantity of fPOM-N and low oPOM-N : fPOM-N ratio for its age. The one garden with a history of cover crop use (Garden #14) had the largest average quantity of oPOM-N and a high oPOM-N : fPOM-N ratio for its age in comparison with other gardens.

PCA on the entire 2011 and 2012 soils dataset identified three independent variables that explained 73% of the variation (Table 2.5; Fig. 2.3). Soil nutrient contents and SOM quantity and quality had the strongest loadings on the first principal component (PC1), which accounted for 41% of the variation. This PC was composed of positive loadings for log(N), log(Mg), log(Ca), and sand, and a negative loading for log(C:N). PC1 showed a strong negative correlation with garden age, suggesting that this PC was dominated by the proportion of recently added, nutrient-rich compost (Fig. 2.4). Since new raised beds in NYC are usually constructed from compost and sandy clean fill, the positive loading of percent sand on PC1 is consistent with this explanation. High values of PC1 were found in younger gardens (5-13 years old), while the lowest values of PC1 were found in older gardens (> 30 years) with lower SOM quantity and quality and a greater proportion of native subsoil (Fig. 2.3).

Principal component 2 (PC2) was dominated by soil texture, with a positive loading for percent sand and negative loading for percent clay. pH also showed a positive loading on PC2, possibly because sandy soils have little capacity to buffer soil pH against alkaline inputs of

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Table 2.5. Principal component eigenvalues, variation explained, and variable loadings for the first three principal components that explain 73% of the variation in the combined 2011 and 2012 soils dataset. Variables with sufficient loading to be considered significant are in bold.

	2011 & 2012 Soils Data		
	PC1	PC2	PC3
Eigenvalue	3.70	1.60	1.30
Variation explained	41%	18%	14%
Variable loadings			
Sand	**0.31**	**0.54**	-0.26
Clay	-0.25	**-0.59**	0.29
Log(N)	**0.48**	-0.15	0.15
Log(C:N)	**-0.33**	0.29	0.17
pH	-0.27	**0.35**	**0.47**
Log(P)	0.25	-0.23	**-0.38**
Log(K)	0.19	-0.21	0.23
Log(Mg)	**0.46**	-0.01	**0.30**
Log(Ca)	**0.33**	0.16	**0.53**
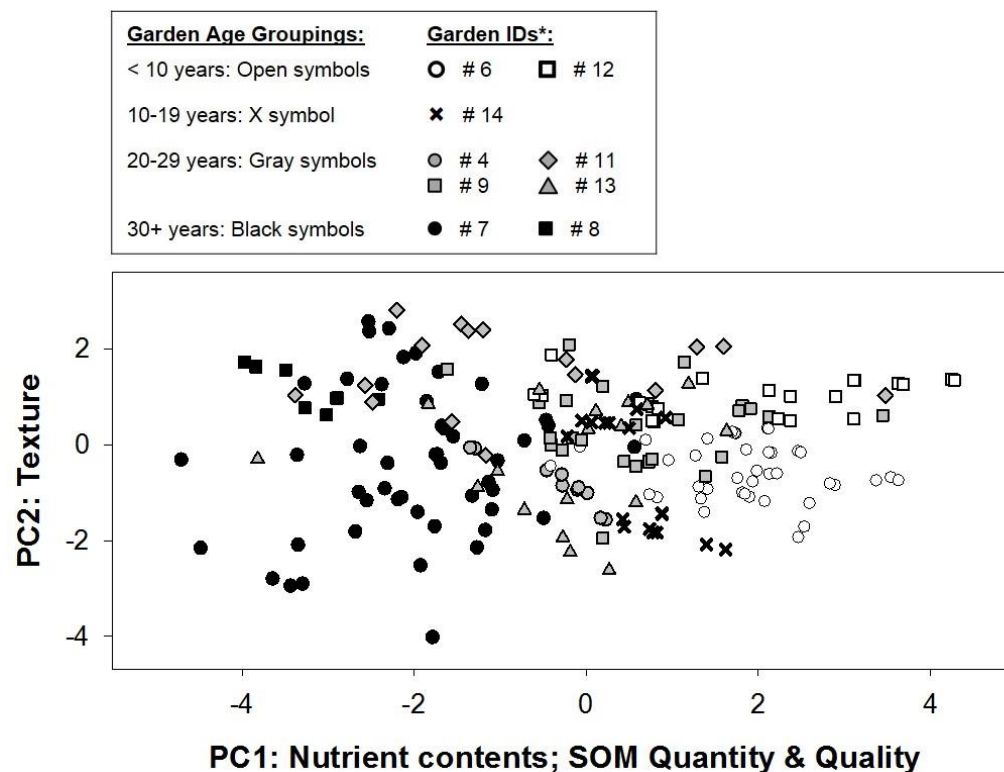
Fig. 2.3. Bi-plot of principal component (PC) scores for PC1 and PC2, which explained 41% and 18%, respectively, of the total variability in the combined 2011 and 2012 soils dataset. For correlations of individual soil variables with each PC, see Table 5. Garden age is indicated as follows: open symbols, < 10 years; "X", 10-19 years; gray symbols, 20-29 years; black symbols, ≥ 30 years. * Garden ID numbers correspond to those in the table of soil properties in Chapter 1 (Gregory et al, 2016). SOM= soil organic matter.
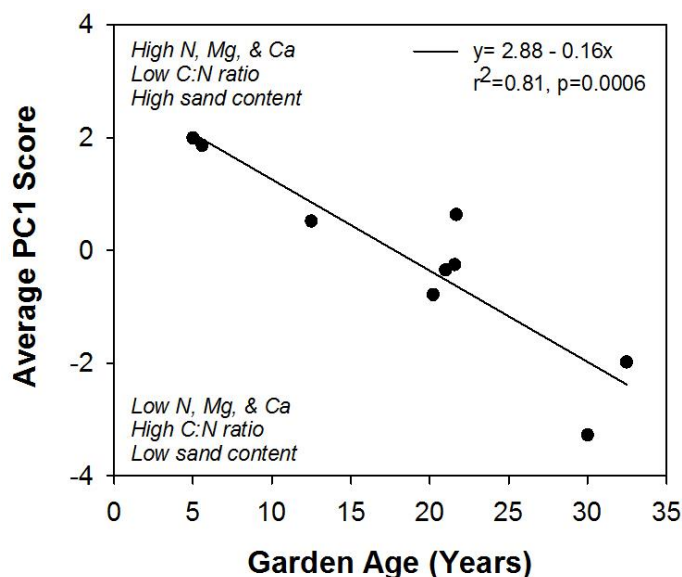
Fig. 2.4. Negative correlation between garden age and the average score for the first principal component for all plots within a garden. High values of PC1 are correlated with higher nutrient contents (N, Mg, Ca), soil organic matter quantity and quality, and sand contents.

concrete dust. The second PC was uncorrelated with garden age and soil C, suggesting that it was influenced by inherent textural properties of the material used to construct beds at each site. Plots from most gardens clustered along PC2 (Fig. 2.3), indicating the effects of common parent material within gardens. The largest exception was Garden #7, where each gardener was largely responsible for procuring materials for her or his own plots.

The results of PCAs conducted on the subsets of 2012 plots used to analyze the effects of soil properties on cover crop performance (Table 2.6) were similar to PCA results from the combined 2011 and 2012 dataset (Table 2.5).

Light availability also varied dramatically across gardens (Table 2.4) due to differences in the surrounding buildings and mature trees. In the Year 2 dataset which was used to analyze the impact of soil and light variability on cover crop performance, plots with the highest soil N contents were found only in gardens with high light availability, such that soil N was

Table 2.6. Results from two Principal Components Analyses (PCAs) identifying major sources of variation in soils for two subsets of 2012 plots used to analyze the effects of soil properties on cover crop performance. The "2012 Low-Moderate N Subset" included Year 2 plots with soil N from 0.6 – 4.2 g N/ kg soil, across the full range of percent transmitted light (8-100%). The "2012 High Light Subset" includes Year 2 plots with 80-100% transmitted light, across the full range of soil N (0.6 – 13 g N/ kg soil). For each PCA, we present principal component eigenvalues, variation explained, and variable loadings for the first three principal components that explain 73% and 80%, respectively, of the variation in each dataset. Variables with sufficient loading to be considered significant are in bold.

	2012: Low-Moderate N Subset			2012: High Light Subset		
	PC1	PC2	PC3	PC1	PC2	PC3
Eigenvalue	3.28	1.77	1.55	3.25	1.81	1.25
Variation explained	36%	20%	17%	41%	23%	16%
Variable loadings						
Sand	**0.33**	**0.50**	-0.20	0.29	**-0.52**	0.15
Square Root(Clay)	-0.27	**-0.54**	0.22	-0.19	**0.63**	-0.20
Log(N)	**0.48**	-0.10	0.18	**0.47**	0.17	0.06
Log(C:N)	**-0.38**	**0.31**	-0.04	**-0.36**	**-0.33**	0.23
pH	**-0.35**	0.25	**0.44**	-0.29	-0.04	**0.61**
Log(P)	**0.36**	-0.18	-0.20	**0.31**	-0.24	**-0.43**
Log(K)	0.15	**-0.34**	**0.43**	0.28	0.00	0.25
Log(Mg)	**0.41**	0.08	**0.34**	**0.45**	0.10	0.21
Log(Ca)	0.07	**0.37**	**0.59**	0.25	**0.36**	**0.47**

significantly correlated with light (data not shown). To separate the effects of soil properties and

light in our analysis of environmental effects on cover crops performance, we used two subsets

of Year 2 data in which light was uncorrelated with both soil N and PC1 for each treatment:

1) The 'Low to Moderate N Subset' (n=152) included plots with soil N contents from 0.6 –
   4.2 g N/ kg soil and the full range of light availability (8-97%).

2) The 'High Light Subset' (n=104) included plots with 80-97% transmitted light and the
   full range of soil N contents (0.6 – 13 g N/ kg soil).

Species composition effects on cover crop performance

Most of the species we selected for cover cropping performed well and produced adequate

biomass to cover soil during the winter; however, there was considerable variation across years

due to biotic factors. In Year 1, preferential seed predation by birds on wheat seed, combined

with powdery mildew (*Blumeria graminis*) outbreaks, devastated the wheat so that wheat

monocultures had little cover and wheat/legume intercrops were dominated by legumes (Table

2.7). In Year 2, we used a disease-resistant rye variety (Aroostock) and protected newly seeded

cover crops from birds with row cover. This resulted in excellent stands for all over-wintering

cover crops (Table 2.8) and significant between-year differences in biomass production and

composition.

Over-wintering cover crops out-performed winter-kill cover crops in terms of biomass, N

fixation, and weed suppression (Table 2.8). Over-wintering cover crops were far more

productive, and over-wintering legumes derived a greater proportion of their N from fixation and

fixed more total N than winter-kill legumes. While oats and oat/pea mixtures had good fall weed

Table 2.7. Average aboveground plant biomass, weed suppression, legume nitrogen (N) fixation, and legume soil N uptake measurements for 4 over-wintering cover crop combinations planted in Fall 2011 and sampled in Spring 2012; these plots (particularly wheat and wheat/legume plots) were severely impacted by seed predation from birds shortly after planting. Different letters within a column represent significant differences between cover crop combinations (Steel-Dwass nonparametric comparisons, all pairs, $p<0.05$). Leg.= Legume. NDFA= N derived from the atmosphere (i.e., N from fixation).

Treatment	Leg. biomass (kg/ha)	Grass biomass (kg/ha)	Total biomass (kg/ha)	Fraction Legume (%)	Weed Suppre-ssion[a]	%NDFA	Leg. N fixed (kg/ha)	Leg. Soil N Uptake (kg/ha)
Over-wintering cover crops								
Crimson clover	5482 a	--------	5482 a	--------	92% a	73% a	118 a	44 a
Hairy vetch	3176 bc	--------	3176 bc	--------	100% a	70% a	118 a	43 a
Wheat/ Crimson clover	4220 ab	160 a	4390 ab	92% b	91% a	74% a	88 a	33 a
Wheat/ Hairy vetch	2892 c	56 a	2952 c	99% a	99% a	64% a	94 a	53 a

[a] Weed suppression was measured as percent reduction in weed biomass in a cover crop plot compared to a control plot in the same garden/management unit.

Table 2.8. Average aboveground plant biomass, weed suppression, and legume nitrogen (N) concentration, N fixation, and soil N uptake measurements for 3 winter-kill and 5 over-wintering cover crop combinations. Winter-kill cover crops were planted late summer 2012 and sampled in late Fall 2012. Over-wintering cover crops were planted in Fall 2012 and sampled in Spring 2013. Different letters within a column represent significant differences between cover crop combinations (p<0.05, Steel-Dwass nonparametric comparisons). Leg.= Legume. NDFA= N derived from the atmosphere (i.e., N from fixation).

Treatment	Leg. biomass (kg/ha)	Grass biomass (kg/ha)	Total biomass (kg/ha)	Fraction Legume (%)	Weed Suppress-ion[a]	%NDFA	Leg. N concent-ration (%)	Leg. N fixed (kg/ha)	Leg. Soil N Uptake (kg/ha)
Winter-kill cover crops									
Field peas	3627 c	--------	3627 d	--------	79% d	29% c	3.91% b	39 cd	96 a
Oats	--------	1473 c	1473 e	41% ab	98% bcd	--------	--------	--------	--------
Oats/Field peas	1229 d	1696 c	2925 d	--------	89% cd	36% c	3.73% b	15 d	30 bc
Over-wintering cover crops									
Crimson clover	8279 a	--------	8279 b	--------	93% bcd	82% b	2.82% c	193 b	42 b
Hairy vetch	5690 b	--------	5690 c	--------	100% a	92% a	5.26% a	274 a	27 c
Winter rye	--------	10423 a	10423 ab	--------	98% abc	--------	--------	--------	--------
Rye/ Crimson clover	2397 cd	8791 ab	11188 ab	25% b	99% abc	86% ab	2.98% c	61 c	10 cd
Rye/ Hairy vetch	5866 b	6960 b	12826 a	51% a	99% ab	79% b	4.07% b	190 b	48 b

[a] Weed suppression was measured as percent reduction in weed biomass in a cover crop plot compared to a control plot in the same garden/management unit.

suppression, this was not maintained into the spring.[6] In contrast, all over-wintering cover crops

showed excellent average spring weed suppression. The treatments showing the most variation

in weed suppression were field peas (coefficient of variation [CV]=35%), oat/pea mixtures

(CV=27%) and crimson clover (CV=14%). Weed suppression by all other treatments was

consistently high and showed CVs of less than 5% across the diverse weed seed banks found in

this study.

The three grass/legume mixtures differed in the competitive balance between grasses and

legumes (Figs. 2.5 & 2.6), with corresponding differences in total N fixed. In oat/pea and

rye/crimson clover mixtures, the grasses suppressed legume growth, as can be seen in pLERs

consistently below 0.5 for the legumes (Figs. 2.6a & 2.6b). Although these two legumes had

slightly higher % NDFA in mixture than in monoculture (though not significantly so), the

reduction in legume biomass in oat/pea and rye/crimson clover mixtures usually resulted in

lower total N fixation compared to their respective legume monocultures (Table 2.8). Total

biomass was also reduced in oat/pea mixtures relative to field pea monocultures due to

suppression of field peas, which had higher potential for biomass production than oats at soil N

contents > 2 g N/kg (Fig. 2.5).

In contrast, rye/vetch mixtures showed even biomass composition and greater vetch

productivity per unit seed sown compared to vetch monocultures (Table 2.8, Figs. 2.5a & 2.6c).

Hairy vetch always produced greater biomass per unit seed sown when grown in mixture with

rye (pLERs > 0.5), and in some cases produced more vetch biomass per unit area in mixtures as

well (pLERs > 1.0). Rye/vetch mixtures also had greater overall productivity compared to the

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[6] Though we did not sample weed biomass in winter-kill plots in the spring (as many gardeners planted these plots
to vegetable crops in early spring), gardeners reported that there was little difference in weed pressure between plots
that had a winter-kill cover crop the previous year and bare fallow plots.
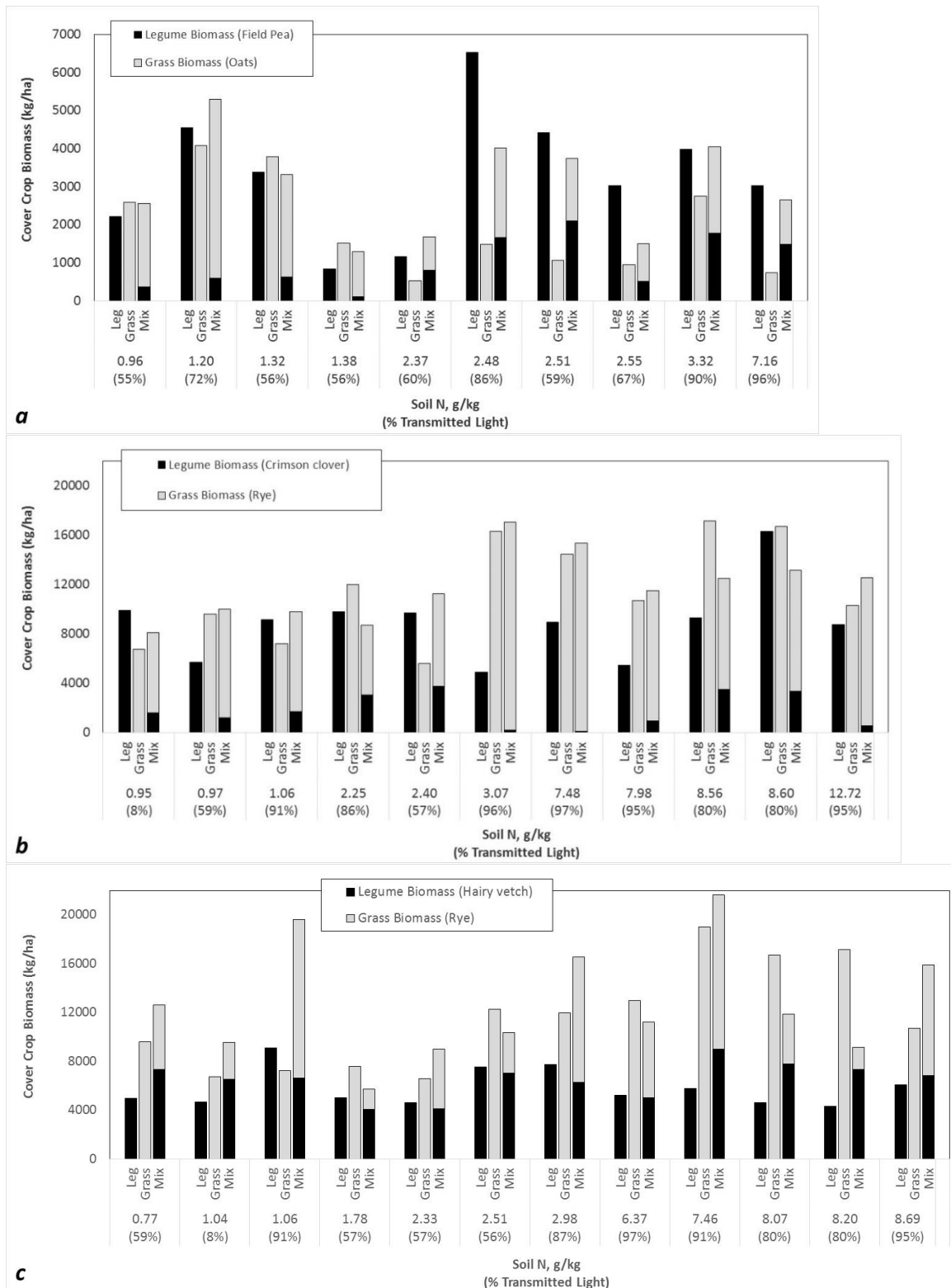
Fig. 2.5. Aboveground cover crop biomass for 2012-2013 plots in which a legume monoculture, grass monoculture, and grass/legume mixture were all grown in the same garden bed/management unit: a) field peas, oats, and oat/pea mixtures; b) crimson clover, rye, and rye/clover mixtures; and c) hairy vetch, rye, and rye/vetch mixtures. Plots are grouped by bed and arranged in order of increasing soil N levels.

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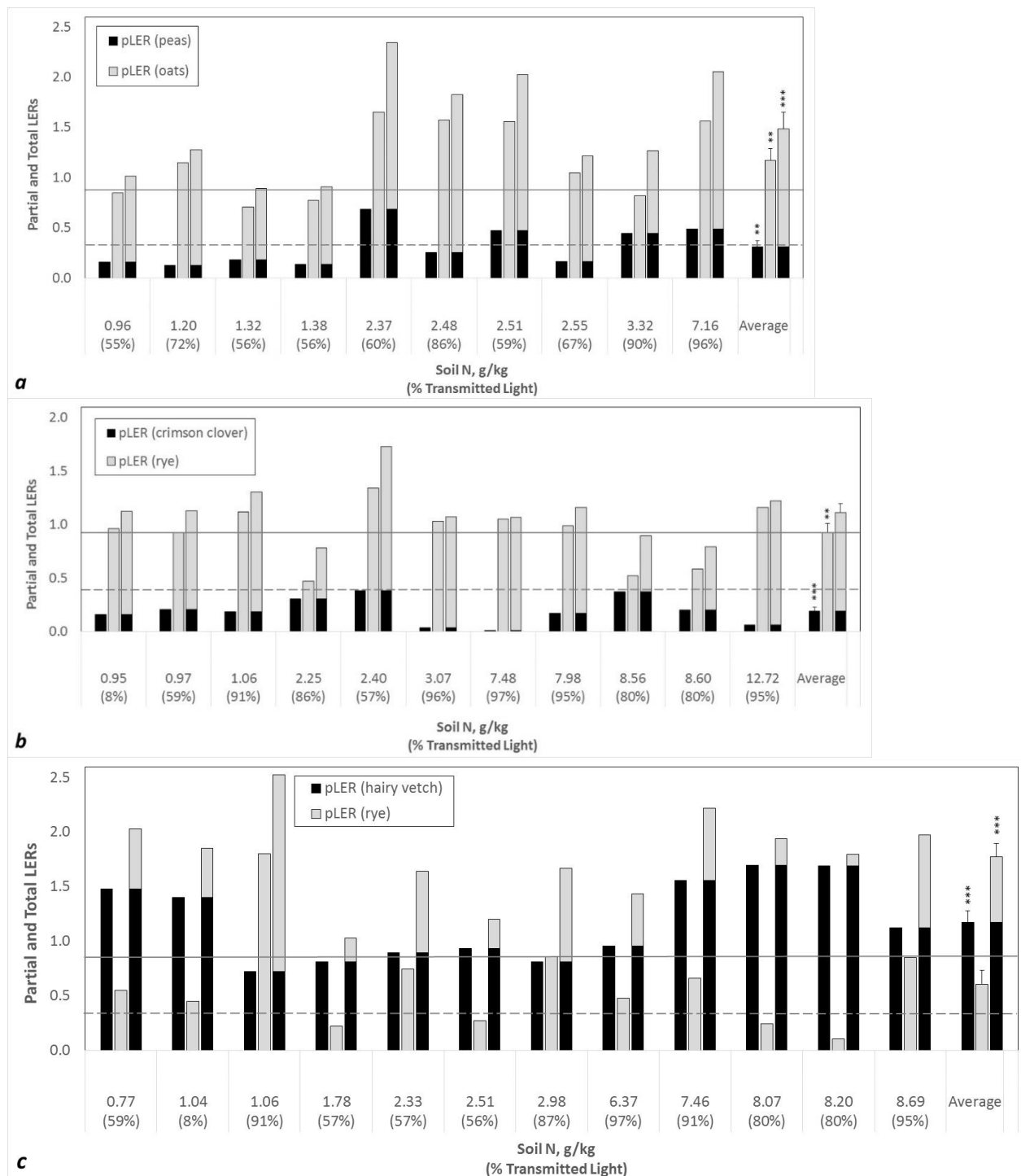
Fig. 2.6. Partial and total Land Equivalent Ratios (LERs) for grass/legume mixtures planted in management units with legume and grass monocultures for comparison: a) oat/pea, b) rye/crimson clover, c) rye/hairy vetch. Black bars represent the partial LER (pLER) of the legume; gray bars the pLER of the grass, and stacked bars the total LER of the mixture. The dotted line at 0.5 indicates the point at which the relative yield of a legume or grass in mixture met its sown proportion. The solid line at 1.0 indicates the point at which the total biomass productivity of the mixture was equal to that of the monocultures. Error bars represent standard errors. Asterisks indicate partial LERs significantly different from 0.5 and total LERs significantly different from 1.0, according to Wilcoxon signed rank tests. Significance levels are as follows: no asterisk indicates p > 0.05; **p < 0.01; ***p < 0.0001.

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component monocultures in all cases (LERs > 1). Surprisingly, relative to vetch monocultures, planting vetch in mixture with rye nearly doubled average vetch N uptake from the soil and decreased its average % NDFA from 92% in monoculture to 79% in mixture (Table 2.8). Lower % NDFA in vetch grown in mixture with rye compared to vetch monocultures was consistent across the range of soil N contents (data not shown), and resulted in lower total N fixation in rye/vetch mixtures compared to vetch monocultures. That said, the average quantity of N fixed in rye/vetch mixtures was the greatest of any of the three mixtures and comparable to total N fixation in crimson clover monocultures (Table 2.8).

Cross-site variability and environmental influences on cover crop performance

Cover crop performance for each treatment varied widely across gardens, likely due to environmental factors (Tables 2.9 & 2.10). Total N fixed was strongly correlated with legume biomass for all treatments except field peas (Table 2.11, Fig. 2.7). Legume N uptake from the soil and % NDFA showed a significant negative correlation in all treatments except oat/pea mixtures (Table 2.11).

In plots with low to moderate soil N contents, light availability was positively correlated with biomass of field peas, oat/pea mixtures, and rye/vetch mixtures (Table 2.12, Fig. 2.8). Hairy vetch and rye/clover biomass showed marginally significant positive correlations with light ($p < 0.10$), while monocultures of crimson clover, oats, and rye were not significantly affected by light availability (Table 2.12). Light did affect the competitive balance between rye and legumes in over-wintering mixtures, with higher light availability favoring rye. For both rye/clover and rye/vetch mixtures, light was positively correlated with grass biomass and

Table 2.9. Average aboveground plant biomass, weed suppression, legume nitrogen fixation, and legume soil N uptake measurements (by garden) for 3 winter-kill cover crop combinations in 10 gardens, planted in late summer 2012 and sampled in late Fall 2012. Garden ID numbers correspond to those in the table of soil properties in Chapter 1 (Gregory et al., 2016). Leg.= Legume; NDFA= N derived from the atmosphere; FP= Field peas; O= Oats.

Garden	Biomass (kg/ha)			% Leg.	Weed Suppression[a]			% NDFA		Leg. N fixed (kg/ha)		Leg. Soil N Uptake (kg/ha)	
	FP	O	O/FP	O/ FP	FP	O	O/FP	FP	O/FP	FP	O/FP	FP	O/FP
4	3725	1008	2630	45%	100%	100%	100%	-----	9%	-----	7	-----	42
6	3079	1427	2595	52%	53%	93%	82%	10%	44%	9	20	83	25
7	3878	2805	3562	16%	82%	100%	75%	36%	59%	49	11	84	7
8	3536	1072	-----	-----	100%	98%	-----	27%	-----	32	-----	86	-----
9	4504	993	2775	85%	97%	100%	97%	22%	41%	39	36	145	48
11	4379	955	2665	35%	100%	98%	100%	53%	31%	82	11	75	24
12	4580	1982	4392	61%	42%	100%	99%	11%	30%	16	30	133	77
13	1438	927	1314	14%	71%	98%	100%	45%	35%	33	3	41	5
14	3846	1012	2846	45%	50%	94%	53%	5%	10%	3	5	135	43
15	2695	2807	3299	10%	96%	100%	99%	51%	57%	76	8	62	6
Overall	**3627**	**1473**	**2925**	**41%**	**76%**	**98%**	**89%**	**29%**	**36%**	**39**	**15**	**96**	**30**

Table 2.10. Average aboveground plant biomass, weed suppression, legume nitrogen fixation, and legume soil N uptake measurements (by garden) for 5 over-wintering cover crop combinations in 10 gardens, planted in Fall 2012 and sampled in Spring 2013. Garden ID numbers correspond to those in the table of soil properties in Chapter 1 (Gregory et al., 2016). Leg.= Legume; NDFA= N derived from the atmosphere; CC= Crimson clover; HV= Hairy vetch; R=Rye.

Garden	Biomass (kg/ha)					% Leg.		Weed Suppression[a]				
	CC	HV	R	R/CC	R/HV	R/CC	R/HV	CC	HV	R	R/CC	R/HV
4	9708	4796	6577	11239	7369	33%	59%	100%	100%	94%	100%	98%
6	7027	5447	13509	14325	13082	3%	38%	86%	100%	99%	99%	100%
7	7855	7124	7953	11043	16124	22%	46%	100%	100%	100%	100%	100%
8	8633	4644	6891	8079	9559	20%	68%	100%	100%	100%	100%	100%
9	7848	5440	8901	8472	10314	36%	63%	100%	100%	99%	99%	100%
11	6037	5598	8244	8282	8706	47%	68%	98%	100%	99%	100%	100%
12	11711	5125	17058	13095	17620	21%	43%	98%	100%	100%	100%	100%
13	5817	6312	11298	13940	9205	34%	64%	64%	99%	94%	99%	93%
14	9827	7730	11984	8715	16546	35%	38%	85%	100%	87%	95%	100%
17	-----	4852	9122	7245	10194	64%	44%	-----	100%	100%	100%	100%
Overall	**8279**	**5690**	**10423**	**11188**	**12877**	**25%**	**51%**	**93%**	**100%**	**98%**	**99%**	**99%**

Continued on next page.

Table 2.10, Continued from previous page.

Garden	% NDFA				Leg. N fixed (kg/ha)				Leg. Soil N Uptake (kg/ha)			
	CC	HV	R/CC	R/HV	CC	HV	R/CC	R/HV	CC	HV	R/CC	R/HV
4	82%	99%	73%	83%	240	255	78	162	55	2	29	31
6	83%	96%	85%	69%	141	275	9	144	31	12	2	58
7	80%	92%	91%	85%	214	383	65	225	53	58	8	39
8	82%	86%	90%	75%	195	209	47	213	43	33	5	71
9	92%	75%	89%	71%	201	195	66	186	21	76	5	76
11	90%	89%	90%	86%	148	254	98	221	16	31	7	30
12	81%	100%	83%	80%	263	265	69	193	50	0	20	46
13	76%	90%	92%	84%	116	291	125	212	38	29	11	41
14	65%	92%	71%	90%	203	394	68	226	112	34	28	25
17	-----	92%	87%	82%	-----	221	128	136	-----	21	19	31
Overall	**82%**	**92%**	**86%**	**79%**	**193**	**274**	**61**	**190**	**42**	**27**	**10**	**48**

Table 2.12. Coefficients of correlation between legume N fixed, %NDFA, legume soil N uptake, and legume biomass for each legume species, in monoculture and in mixture with a grass, planted in 2012-2013. Significant correlations (p < 0.05) are highlighted in gray. Significance levels are as follows: *p < 0.05; **p < 0.01; ***p < 0.0001. Leg.= Legume; NDFA= N derived from the atmosphere.

Treatment	Leg N fixed (kg/ha)			% NDFA		Leg. Soil N Uptake (kg/ha)
	Leg. biomass (kg/ha)	Leg. Soil N Uptake (kg/ha)	%NDFA	Leg. biomass (kg/ha)	Leg. Soil N Uptake (kg/ha)	Leg. biomass (kg/ha)
Field peas	0.32	−0.06	0.76 **	−0.22 **	−0.56 **	0.86 ***
Oats/Field peas	0.83 ***	0.63 **	0.25	−0.18	−0.41	0.94 ***
Crimson clover	0.87 ***	0.03	0.29	−0.06	−0.89 ***	0.32
Hairy vetch	0.98 ***	0.40	0.07	−0.06	−0.72 ***	0.53 **
Rye/ Crimson clover	0.82 ***	0.14	0.15	−0.33	−0.93 ***	0.57 *
Rye/ Hairy vetch	0.77 ***	−0.08	0.64 **	0.23	−0.76 ***	0.33
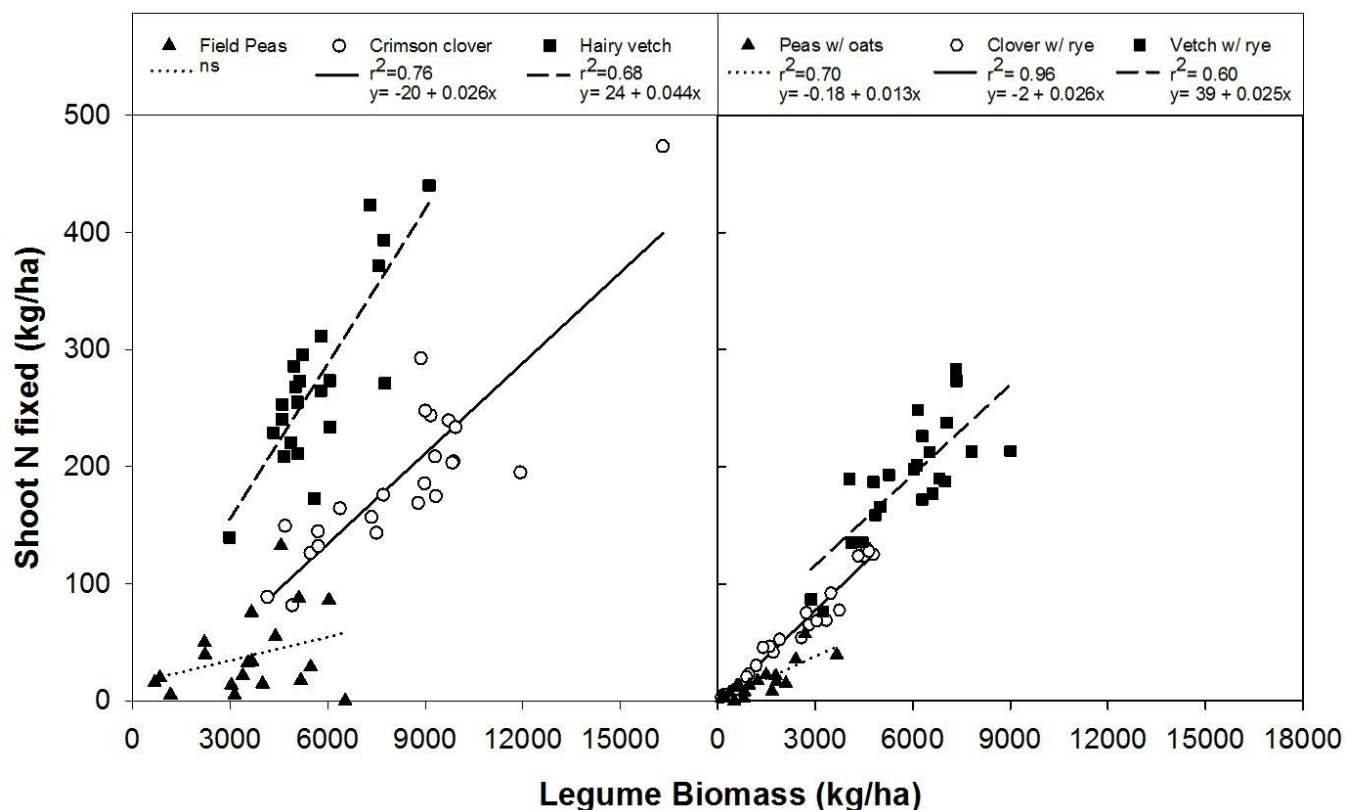
Fig. 2.7. Relationships between aboveground legume biomass and shoot N fixed for cover crops planted in 2012-2013. At left, legume monocultures; at right, legumes in mixtures. All regression equations shown are significant at p < 0.001.

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Table 2.12. Effects of light availability on cover crop biomass, biomass composition, and legume N fixation and soil N uptake for the subset of Year 2 plots with low-to-moderate soil N (0.6 – 4.2 g N/ kg soil) across the full range of % transmitted light (8-100%). The table shows coefficients of correlation between % transmitted light and cover crop performance measures for each treatment. Significant correlations are presented in bold and highlighted in gray. Significance levels are as follows: *p < 0.05; **p < 0.01. Leg.= Legume. NDFA= N derived from the atmosphere.

Treatment	Correlations with % Transmitted Light						
	Leg. biomass (kg/ha)	Grass biomass (kg/ha)	Total biomass (kg/ha)	Fraction Legume (%)	%NDFA	Leg. N Fixed (kg/ha)	Leg. Soil N Uptake (kg/ha)
Field peas	**0.63 ****	-----	**0.63 ****	-----	-0.16	0.26	0.50
Oats	-----	0.27	0.27	-----	-----	-----	-----
Oats/Field peas	0.35	0.29	0.50	0.26	-0.10	0.11	0.35
Crimson clover	0.26	-----	0.26	-----	-0.16	0.20	0.25
Hairy vetch	0.55	-----	0.55	-----	-0.01	0.57	0.21
Winter rye	-----	0.30	0.30	-----	-----	-----	-----
Rye/ Crimson clover	-0.31	0.49	0.42	-0.44	0.10	-0.30	-0.01
Rye/ Hairy vetch	0.08	**0.70 ****	**0.66 ***	**-0.65 ***	0.19	-0.16	-0.32
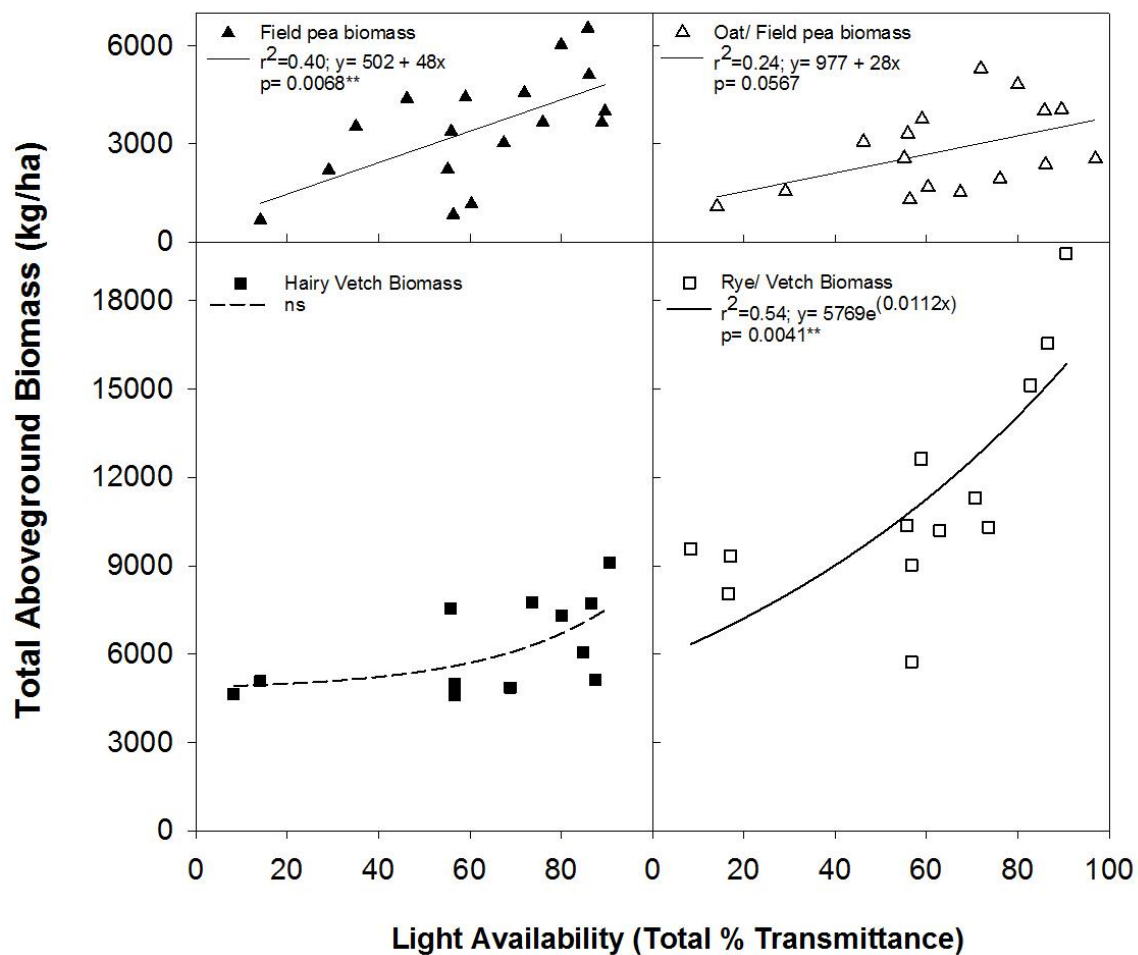
Fig. 2.8. Relationships between light availability and total cover crop biomass for selected treatments in the subset of Year 2 plots with low-to-moderate soil N (0.6 – 4.2 g N/ kg soil): field peas, oat/field pea mixtures, hairy vetch, and rye/hairy vetch mixtures.

negatively correlated with fraction legume biomass (Table 2.12). This suggests that in mixtures, rye responds to light with increased growth to a greater degree than the legumes, particularly crimson clover.

We found the strongest effects of soil fertility on biomass and N fixation in the subset of data with high light availability and the full range of soil N (Table 2.13). In these plots, soil fertility and N availability affected N fixation directly in field pea monocultures by decreasing % NDFA, and indirectly in oat/pea and rye/clover mixtures through effects on mixture biomass composition. PC1 (a measure of soil fertility and N-rich SOM) was negatively correlated with % NDFA and N fixed for field pea monocultures, suggesting that high N availability inhibited N fixation. Increasing soil fertility and N availability (i.e., higher PC1 and/or N) increased fraction legume biomass in oat/pea mixtures and decreased it in rye/crimson clover mixtures, with corresponding effects on total N fixed (Table 2.13, Fig. 2.9). For oat/pea mixtures, PC1 was also positively correlated with legume biomass, and therefore with legume N fixed and soil N uptake (Table 2.13). The opposite was true for rye/crimson clover mixtures: PC1 was negatively correlated with legume biomass and N fixed, though these correlations were not statistically significant. There was also a marginally significant negative correlation between PC1 and % NDFA in rye/clover mixtures. Interestingly, crimson clover and hairy vetch monocultures maintained high % NDFA (above 60% and 80%, respectively) across the range of soil PC1 values and N contents (data not shown), and PC1 did not significantly affect total N fixation for either of the over-wintering legume monocultures[7] (Table 2.13).

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[7] For hairy vetch monocultures in the High Light dataset, legume N fixed showed a marginally significant negative correlation with PC1. However, this trend was driven by two plots with very high biomass and low values of PC1; removing these plots resulted in no significant effects of PC1.

Table 2.13. Effects of PC1 (representing soil fertility and organic matter quantity and quality) on cover crop biomass, biomass composition, and legume N fixation and soil N uptake for two subsets of Year 2 plots. The "2012 Low-Moderate N Subset" included plots with soil N from 0.6 – 4.2 g N/ kg soil, across the full range of percent transmitted light (8-100%). The "2012 High Light Subset" includes plots with 80-100% transmitted light, across the full range of soil N (0.6 – 13 g N/ kg soil). Significant correlations are presented in bold and highlighted in gray. Significance levels are as follows: *p < 0.05; **p < 0.01. Leg.= Legume. NDFA= N derived from the atmosphere.

| Treatment | Correlations with PC 1 (Soil Fertility; OM Quantity & Quality; Sand) | | | | | | | | | | | | | |
| | Low-Moderate N Subset | | | | | | | High Light Subset | | | | | | |
	Leg. biomass (kg/ha)	Grass biomass (kg/ha)	Total biomass (kg/ha)	Fraction Legume (%)	%NDFA	Leg. N Fixed (kg/ha)	Leg. Soil N Uptake (kg/ha)	Leg. biomass (kg/ha)	Grass biomass (kg/ha)	Total biomass (kg/ha)	Fraction Legume (%)	%NDFA	Leg. N Fixed (kg/ha)	Leg. Soil N Uptake (kg/ha)
Field peas	-0.05	-----	-0.05	-----	-0.20	-0.18	0.17	-0.10	-----	-0.10	-----	**-0.77 ***	**-0.75 ***	0.24
Oats	-----	**-0.44 ***	**-0.44 ***	-----	-----	-----	-----	-----	-0.11	-0.11	-----	-----	-----	-----
Oats/Field peas	0.36	**-0.54 ***	-0.30	0.48	**-0.52 ***	0.12	0.44	**0.85 ***	-0.45	0.32	**0.80 ***	-0.36	0.74	**0.76 ***
Crimson clover	-0.17	-----	-0.17	-----	-0.15	-0.31	0.02	0.16	-----	0.16	-----	0.19	0.09	-0.33
Hairy vetch	-0.02	-----	-0.02	-----	-0.16	-0.23	0.10	**-0.59 ***	-----	**-0.59 ***	-----	0.41	-0.57	-0.53
Winter rye	-----	**0.50 ****	**0.50 ****	-----	-----	-----	-----	-----	**0.59 ****	**0.59 ****	-----	-----	-----	-----
Rye/ Crimson clover	0.12	0.24	0.31	0.11	-0.17	0.09	0.18	-0.30	0.44	0.40	-0.39	-0.47	-0.35	0.20
Rye/ Hairy vetch	-0.33	0.00	-0.11	-0.18	-0.18	-0.48	0.02	0.14	-0.56	-0.55	0.53	-0.07	0.26	0.27
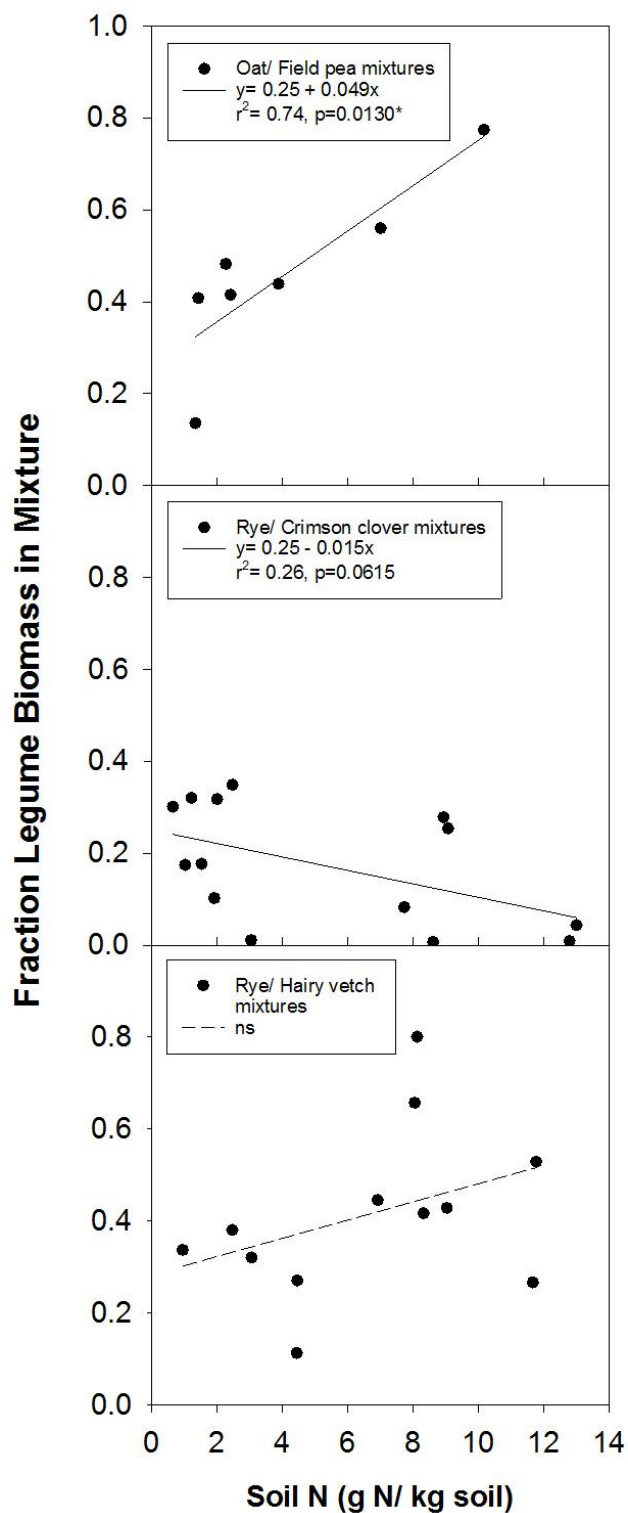
Fig. 2.9. Relationships between soil N and the fraction legume biomass for grass/legume mixtures in the subset of Year 2 plots with high light availability (80-100%) and across the range of soil N levels (0.6 – 13 g N/ kg soil): Oats/ field peas (top panel), rye/ crimson clover mixtures (middle panel), and rye/ hairy vetch mixtures (bottom panel).
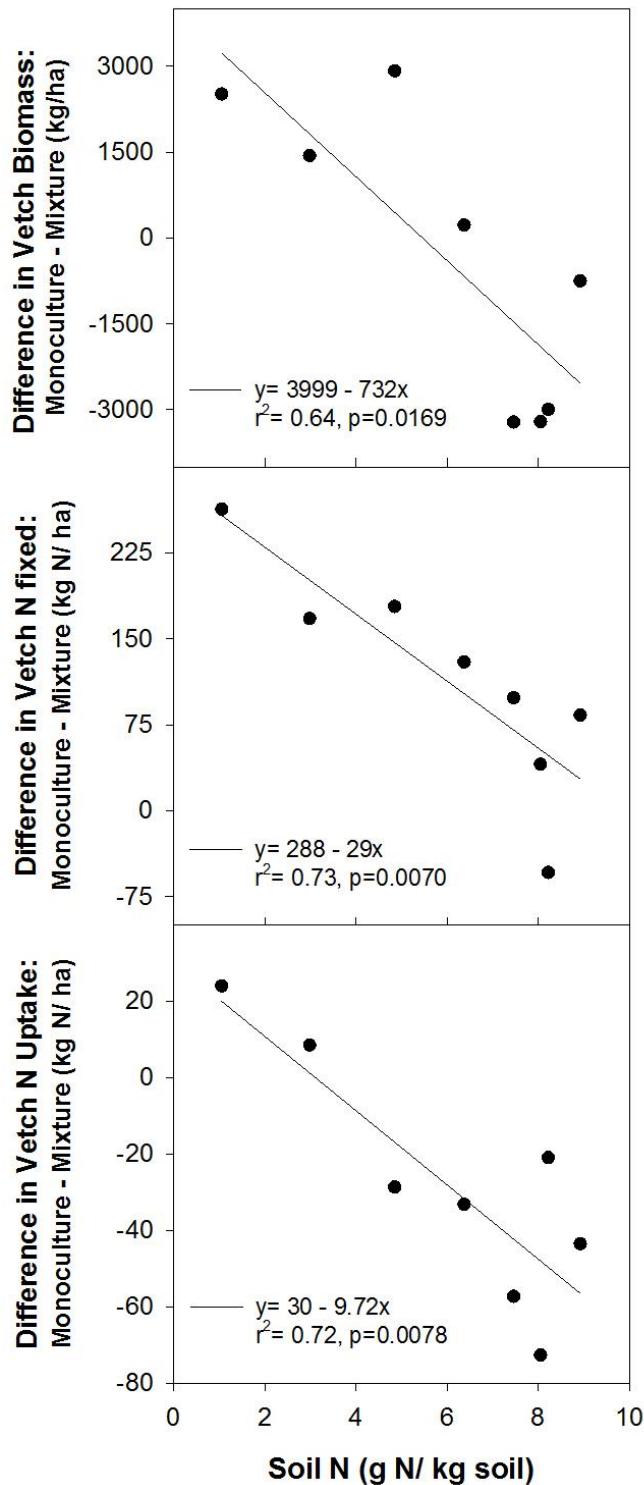
Fig. 2.10. Relationships between soil N and the difference in vetch performance in monoculture and in mixture with rye for paired plots grown under similar soil and light conditions. Plots are from the subset of Year 2 data with high light availability (80-100%) and across the range of soil N levels (0.7 – 13 g N/ kg soil). Differences in vetch performance measures are for vetch in monoculture, *minus* the vetch in the paired rye/vetch mixture plot, and are shown for: legume biomass (top panel), legume N fixed (middle panel), and legume soil N uptake (bottom panel).

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While soil N availability did not significantly affect % NDFA or N fixed in rye/vetch mixtures (Table 2.13), it did impact the *relative* performance of vetch in monoculture and mixture with rye for paired plots grown under similar soil and light conditions (Fig. 2.10). Soil N was significantly negatively correlated with the differences (monoculture – mixture) in vetch biomass, N fixed, and legume N uptake from the soil (Fig. 2.10) and positively correlated with the difference in vetch % NDFA (though the latter was not statistically significant). We observed the same trends for soil C (data not shown). In other words, as SOM and N contents increased, vetch in monoculture had a decreasing advantage over rye/vetch mixtures with respect to legume biomass and legume N fixed. At the same time, rye/vetch mixtures showed even greater legume N uptake from the soil relative to vetch monocultures as soil N increased.

Field-based indicators of cover crop performance

Gardeners' visual estimates of cover crop performance successfully identified differences between years and cover crop treatments and usually corresponded well with quantitative sampling data (Figs. 2.11, 2.12, & 2.13). Visual estimates tended to slightly over-estimate percent legume in oat/pea mixtures and under-estimate percent legume in rye/clover and rye/vetch mixtures (Fig. 2.12). Gardeners' assessments of weed cover showed rough correspondence with weed biomass for Spring, but not Fall, observations (Fig. 2.13). For all sampling dates, there were several plots where gardeners estimated 10-30% weed cover, but no weeds were present in biomass samples. In these cases, gardeners' assessments may have been influenced by weeds growing on the edges of cover crop plots, which were not captured in biomass samples taken from the center of plots.
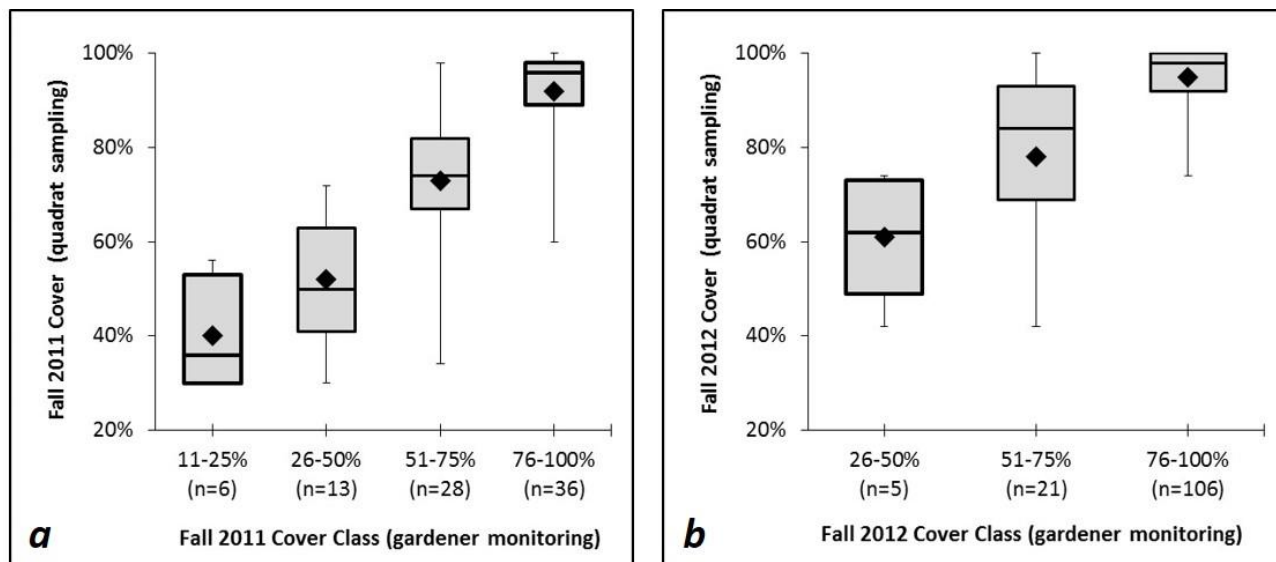
Fig. 2.11. Boxplots of researcher cover measurements (using grid sampling) grouped by the percent cover classes assigned by gardeners (using visual estimates) for legumes and grass/legume mixtures in: a) Fall 2011 and b) Fall 2012. Boxes span the interquartile range for cover measurements within each assigned cover class, with the line marking the median. Whiskers span the range of cover measurements, while diamonds mark the average within each assigned cover class.
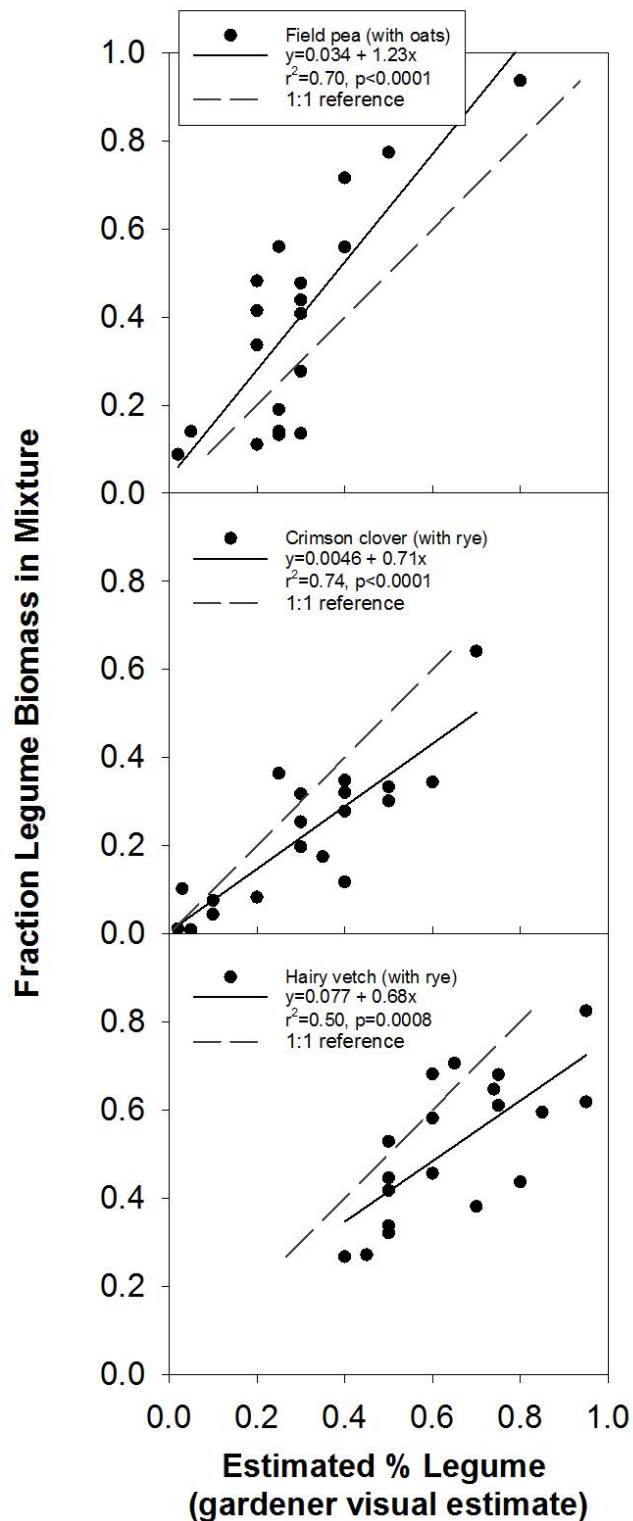
Fig. 2.12. Relationships between gardener visual estimates of percent legume in grass/legume mixtures and fraction legume biomass determined by sampling for mixtures planted in 2012-2013: oats/peas (top panel), rye/ crimson clover (middle panel), and rye/ hairy vetch (bottom panel). Solid lines represent gardener visual estimates, while dashed lines are 1:1 reference lines.
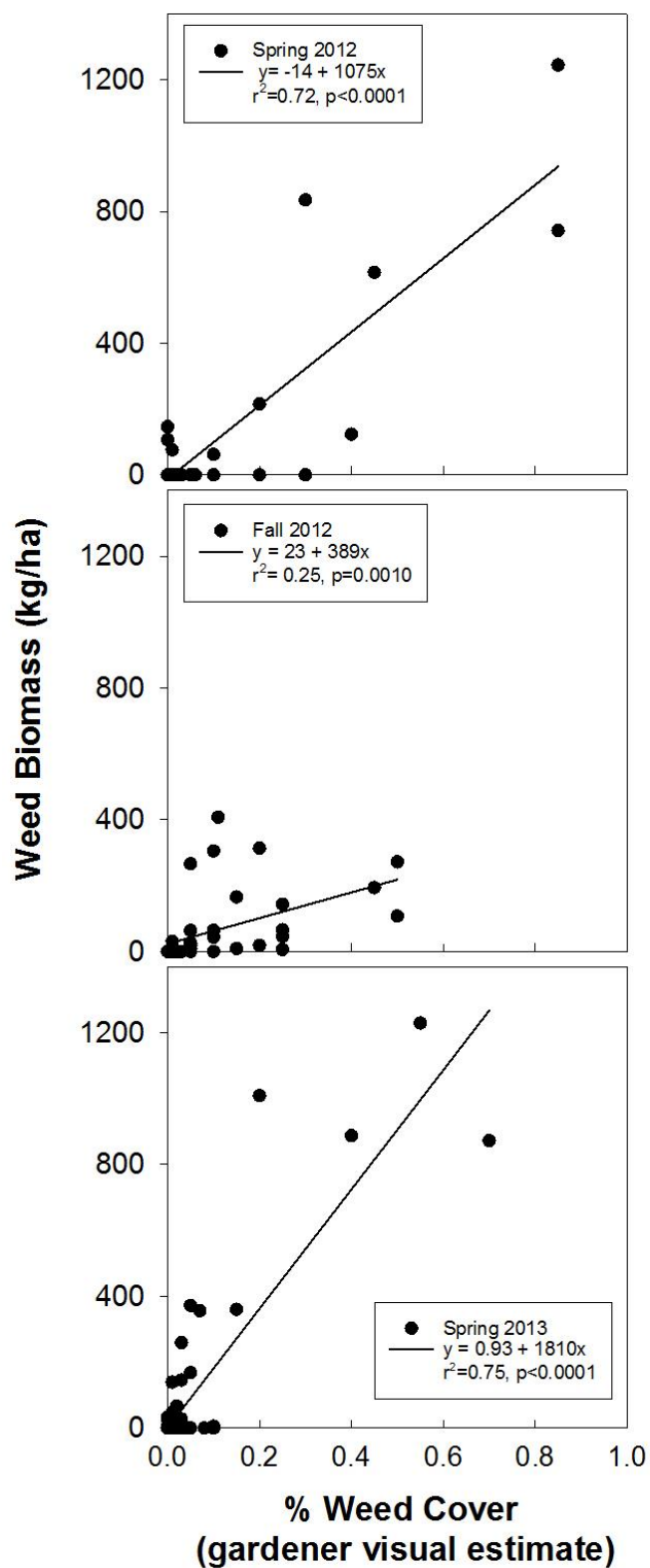
Fig. 2.13. Relationships between gardener visual estimates of percent weed cover and weed biomass determined by sampling in: Spring 2012 (over-wintering cover crops, top panel), Fall 2012 (winter-kill cover crops, middle panel), and Spring 2013 (over-wintering cover crops, bottom panel).

Field-based indicators were less reliable for predicting cover crop biomass from cover and height, or predicting N fixation from nodule color. Multiple regression models showed that for legume cover crops, plant height and/or percent cover estimates were not significant predictors of biomass (data not shown). Models for grass cover crop biomass showed only slightly better fit, with plant height (but not cover) a significant predictor of oat biomass (r^2=0.57; p<0.0001) and both height and cover significant predictors of rye biomass (r^2=0.62; p<0.0001 for height and p=0.018 for cover). However, 40-50% of the variation in grass biomass remained unexplained even when accounting for plant height and cover. Nodule color classes -- at least as determined from examining the roots of two plants per plot -- also did not capture within-species differences in % NDFA (Fig. 2.14). Within a treatment, plots placed into each of the nodule color classes generally showed similar spreads in % NDFA, with no pattern of increasing % NDFA with more pink or red color inside the nodules.

Gardener perspectives on cover crop management and impacts

Cover crop management challenges and solutions

Most of gardeners' management challenges were associated with over-wintering cover crops, but they also perceived more beneficial effects of these cover crops compared with winter-kill cover crops (Tables 2.14 & 2.15). Some gardeners reported difficulty cutting down over-wintering cover crops and preparing the plots for planting vegetables, particularly during our first year of research. We encouraged gardeners to use the 'cut-and-mulch' technique, which involves waiting for cover crops to flower, then chopping the shoots with hedge shears, leaving the residue as mulch on the soil surface, and digging holes only to set transplants. However, many gardeners were accustomed to turning the soil each year and chose to incorporate the cover
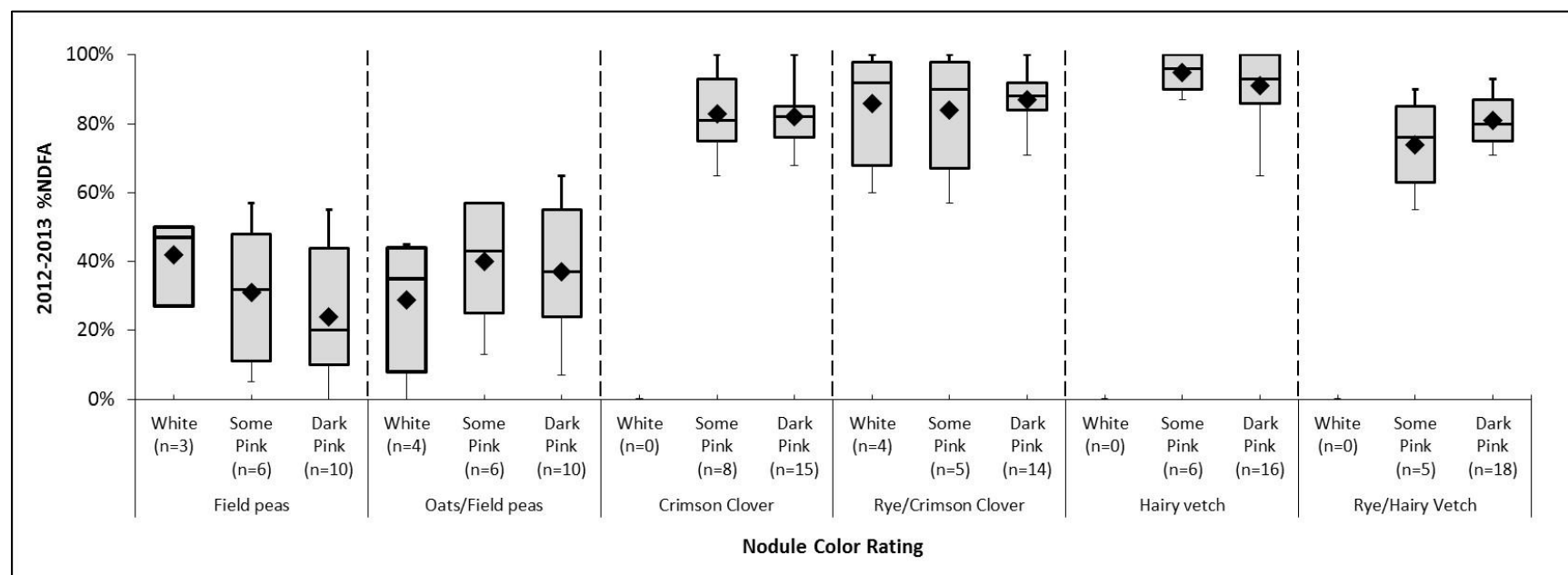
Fig. 2.14. Boxplots of 2012-2013 %NDFA measurements at sampling, grouped by the nodule color ratings assigned by gardeners prior to sampling, and by treatment. Boxes span the interquartile range (25th – 75th percentile values) for %NDFA measurements, with the line marking the median. Whiskers span the range of %NDFA measurements, while diamonds mark the average within each assigned nodule color rating. NDFA= N derived from the atmosphere.

Table 2.14. Commonly mentioned cover crop management challenges and solutions reported by gardeners in follow-up interviews in July-August 2012 (Year 1) and 2013 (Year 2), two to three months after terminating over-wintering cover crops. These themes emerged from gardeners' responses to open-ended questions about cover crop management. OW = over-wintering, WK = winter-kill.

Cover Crop Management Challenges & Example Comments		Solutions to Management Challenges & Example Comments	
Managing OW cover crop biomass in Spring	• Gardeners who incorporated the cover crops found it difficult to bury so much residue. (Year 1, from informal conversations) • "The plants were huge! I had to compost a lot of it." (Year 1)	**"Cut-and-mulch" technique**	• "The cut-and-mulch technique was easy, and works well for transplants." (Year 2; many similar comments – though some gardeners felt even this was too much work) • "It's easier to just cut the cover crops and leave them as mulch without tilling." (Year 2)
Preparing a seedbed for direct-seeded crops	• "The cut-and-mulch technique was not good for seeds. I had to push apart the mulch and dig a trench." (Year 2)	**Zone tillage**	• "I left most mulch on the soil, but in places where I was going to plant seeds, I turned the chopped shoots under and waited two weeks to plant." (Year 2)
Finding efficient tools for cutting down OW cover crops	• "It would be nice to find a tool to cut more stems near the ground with one pass." (Year 1, gardener used scissors to cut down cover crops) • "Using hedge shears [to cut down the cover crops] was a LOT of work at our scale." (Year 2, gardener at a site with large urban-farm beds and > 100 m^2 in OW cover crops)	**Hedge shears (typical garden scale)** **Small machinery (urban farm scale)**	• "The hedge shears were easy to use. I will do cut-and-mulch again." (Year 2; many similar comments) • "We did a couple passes mowing with a BCS [walk-behind tractor] rototiller, raked [the cover crop shoots] into windrows and mowed again because there is a lot of plant material. We left it rough and planted tomatoes. Not having to create a seed bed worked well time-wise, and the plants were healthy." (Year 2, urban farm coordinator)
Delayed planting of vegetable crops in Spring following OW cover crops	• "It's hard to adjust vegetable planting plans to include OW cover crops. It would be nice to have cover crops that let you plant early in some places" (Year 1; many similar comments). • "The only drawback with OW cover crops is that it takes longer to plant in the spring, since you have to wait for the cover crops to mature" (Year 2; many similar comments). • "Vetch takes a long time to flower. Waiting until June to plant was a little hard." (Year 2, when cool spring temperatures delayed cover crop growth and flowering.)	**Rotation planning** **Use a combination of OW and WK cover crops**	• "I need to plan rotations better with the cover crops and consider what [vegetable crops] I'm going to plant next." (Year 2) • "I will do some WK and some OW next year, and then rotate." (Year 2) • "Pea and oat/pea plots were easy to plant in early spring" (Year 2).

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Table 2.15. Perceived benefits of cover crops during the season following cover crop termination, as reported by gardeners in follow-up interviews in July-August 2012 and 2013 (two to three months after terminating over-wintering cover crops). OW = over-wintering, WK = winter-kill.

Perceived Cover Crop Benefits	% of Interviewed Gardeners			Example Comments
	Year 1: OW	Year 2: OW	Year 2: WK	
Sustained weed suppression	88%	100%	33%	• "There were no weeds for a long time [in the OW cover crop plots] in spring. Other gardeners had weeded three times before I saw anything. With the cover crop mulch surrounding the transplants, weeds didn't strangle them and the crops were healthier." • "OW cover crop mulch made a huge difference in decreasing weeds. There was no real difference in the WK plots [compared to plots that were not cover-cropped]." • "The mulch [from OW cover crops] is great and takes a long time to decompose."
Soil moisture & drainage	71%	94%	33%	• "The soil holds more water; it doesn't dry up as quickly as it used to. The plants survived dry spells well." • "Soil moisture improved in the OW cover crop plots -- probably a combination of organic matter and mulch. During hot spells, the OW cover crop plots needed less water." • "We've had some extremely hot days, and the mulch helped keep the moisture in."
Soil tilth	65%	71%	22%	• "My first year [in the community garden] the soil was brown and hard to dig and plant. This year [after a rye/vetch cover crop] there were more worms and beetles, and when I cover the transplants back up, the soil is softer. The roots decomposed so they were not a problem for planting." • "I like what it [cover cropping] does for soil texture… you can stick your arm in up to the elbow!" • "The dirt is softer and easier to dig. The plants are growing better."
Soil fertility / Nutrient supply to crops [a]	35% +	76%	56%	• "The cucumbers grew better, and I used less fertilizer on the peppers." • "There were adequate nutrients for my vegetables without any compost or fertilizer." • "The crops have nice, broad, green leaves, and I didn't put any fertilizer. Last year, when I planted where there weren't cover crops, the leaves were so tiny."

[a] In Year 1, we did not ask gardeners about perceived benefits of the cover crops for soil fertility or nutrient supply to vegetable crops. The 35% of gardeners noted as observing such benefits in Year 1 mentioned (without prompting) better growth of vegetables following the cover crops, with less soil amendments or fertilizers than in past years. As such, this represents a minimum percentage of gardeners who may have observed soil fertility/ crop nutrition benefits. In Year 2, we asked all gardeners about possible improvements in soil fertility due to the cover crops, as reflected in vegetable crop performance relative to past years.

crops. These gardeners found it difficult to bury so much residue with hand tools. Those who did use the cut-and-mulch approach (about half of gardeners in the first year) were generally pleased with the results. The fact that their vegetable crops did well allayed other gardeners' concerns about transplanting vegetables into a 'rough' seedbed with cover crop shoots on the soil surface and roots undisturbed, with the exception of holes for the transplants.

In Year 2 we held a workshop where we demonstrated how to cut down over-wintering cover crops and leave the chopped shoots as mulch for transplants. We also distributed hedge shears for each garden and taught gardeners how to sharpen and maintain them. When we followed up with gardeners in mid-summer, about 80% had used the 'cut-and-mulch' technique and found it "easy." Most affirmed that they would use this method in the future (Table 2.14). In addition to being less work than incorporating cover crops into the soil, gardeners also noted that cover crop mulch around vegetable transplants prevented weed growth, conserved soil moisture, and kept crop plants clean (Tables 2.14 & 2.15). Several gardeners noticed that the rough seedbed and thick mulch was not ideal for direct-seeded crops, however. Some of these gardeners found that tilling narrow strips and waiting ten days to two weeks to plant was sufficient to establish direct-seeded crops; it was not necessary to till the entire plot (Table 2.14). Most gardeners found the hedge shears an effective tool for cutting down over-wintering cover crops, noting that the shears cut large swaths of cover crop stems quickly. At only one garden – which had larger beds and more than 100 m^2 of over-wintering cover crops – did gardeners report that hedge shears were insufficient. An urban farm participating in this study used a BCS (two-wheel, walk-behind tractor) to mow the cover crops several times, and found this satisfactory for creating mulch to transplant into (Table 2.14).

Adjusting the timing of vegetable crop plantings was another challenge for gardeners.

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Many noted that waiting for over-wintering cover crops to flower -- which maximizes biomass and legume N contributions and ensures cover crop kill -- also delayed vegetable crop planting in the Spring (Table 2.14). While this did not interfere greatly with planting dates for warm-season crops (e.g., tomatoes, zucchini), it did preclude early spring plantings of cool-season vegetables (e.g., kale, greens) in the beds planted to over-wintering cover crops. In response to these concerns, in our second year we offered a workshop on planning vegetable crop rotations that incorporate cover crops,[8] and also included winter-kill cover crop options. These two adjustments addressed gardeners' concerns about the cover crops interfering with vegetable planting schedules. In Year 2 follow-up interviews, several gardeners indicated that they would plan rotations more carefully and consider which vegetable crops would be planted after different cover crops (Table 2.14). Gardeners also expressed interest in using a combination of over-wintering and winter-kill cover crops. By rotating among these two classes of cover crops, gardeners felt they could achieve both soil quality improvement (primarily with over-wintering cover crops) while allowing early spring plantings in some beds each year (following winter-kill cover crops).

Perceived cover crop impacts

During the growing season following cover crop plantings, gardeners perceived more beneficial effects (i.e., weed suppression, improved soil moisture and tilth, and soil fertility) of over-wintering cover crops compared to winter-kill cover crops. Gardeners were slightly more likely to report positive impacts of over-wintering cover crops in the second year of research than in the

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[8] The workshop outline is available at: http://tinyurl.com/GardenCalendarWorkshop, and garden planning handouts are available at: http://tinyurl.com/GardenPlanning7b (USDA Zone 7) and http://tinyurl.com/GardenPlanning6a (USDA Zone 6).

first (Table 2.15).

Weed suppression was the most frequently observed benefit of over-wintering cover crops, with 88% of gardeners in Year 1 and 100% of gardeners in Year 2 reporting weed control that lasted well into the vegetable growing season. Gardeners attributed this to mulch from cover crop shoots, particularly rye in Year 2. Most gardeners also observed that over-wintering cover crops improved soil moisture and tilth (Table 2.15). Many gardeners reporting perceived benefits for soil moisture noted that mulch from over-wintering cover crops helped prevent water loss due to evaporation. However, gardeners who incorporated cover crops also reported soil moisture benefits, indicating potential effects on soil water-holding capacity. When asked in Year 2 to evaluate potential nutrient supply benefits (as reflected in vegetable crop performance relative to past years, considering other nutrient applications), about three-fourths of gardeners perceived that over-wintering cover crops had a positive impact on soil fertility and crop nutrition (Table 2.15).

In contrast to over-wintering cover crops, relatively few gardeners (22-33%) noted substantial benefits of winter-kill cover crops in terms of weed suppression or soil moisture and tilth after a single season. Slightly over half thought that winter-kill cover crops supplied some nutrients to succeeding crops (Table 2.15). Where gardeners noted benefits of both over-wintering and winter-kill cover crops, they almost always emphasized that the impacts of over-wintering cover crops were more pronounced.

Discussion

In this study we tested winter cover crops suitable for northern temperate climates across the diverse soil and light conditions of Brooklyn, NY community gardens. Our results show that

these cover crops could provide ecosystem services that support food production and environmental sustainability in urban food gardens, including organic matter inputs from cover crop biomass, improved soil moisture and tilth, weed suppression, and legume N fixation. However, we also documented wide variation in environmental conditions and cover crop performance across gardens. Our findings suggest that management goals, environmental conditions, and cover crop species characteristics should all be factored into cover crop selection for urban gardens. To adopt and refine cover cropping practices, urban gardeners also need assistance developing rotation plans that incorporate cover crops and access to tools and small machinery to manage residues from over-wintering cover crops.

Brooklyn garden soils: Influences of urban context, garden age, and management

Several characteristics of Brooklyn garden soils distinguished them from agricultural field soils and have important implications for sustainable soil management. In urban settings, raised-bed soils are often constructed with a high proportion of compost mixed with sand, introducing large quantities of fPOM into new garden beds. Within the dataset of urban garden soils, garden age and management practices both impacted soil properties. Principal components analyses confirmed the strong influence of compost additions and garden age: While young gardens with a high proportion of recently added compost had high labile organic matter and nutrient contents, older gardens had lower organic matter quantity and quality and reduced concentrations of plant nutrients. POM data indicated the potential importance of management practices, as cover crop use in Garden #14 was associated with a higher oPOM-N : fPOM-N ratio than would be expected based on garden age. This is consistent with other studies demonstrating that cover crops may enhance soil aggregation and physical protection of SOM, likely due to aggregate formation around decomposing root fragments (Wander et al., 1994; Puget and Drinkwater,

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2001; Kong and Six, 2010).

Compared to agricultural field soils, these urban garden soils are in very early stages of soil formation and the majority of soil organic N is located in fPOM, followed by oPOM and stabilized SOM. Unlike oPOM, fPOM is not protected by interactions with mineral particles, so it is accessible to decomposers. For this reason, the quantity of fPOM is correlated with N mineralization and soil-derived N uptake by crops (Wander, 2004; Marriott and Wander, 2006a; b). Since Brooklyn garden soils contain large amounts of N in fPOM, N availability to plants from SOM mineralization is likely much greater than in field soils, where fPOM accounts for just 2-3% of total soil N (Wander and Bidart, 2000; Schipanski et al., 2010). As these anthropogenic soils age, oPOM-N : fPOM-N ratios tended to increase; however, even the oldest garden (33 years) still had more fPOM-N than oPOM-N. Rates of SOM occlusion in aggregates may be low in these urban garden soils due to their sandy textures, as sand has less reactive surface area to bind OM in comparison to silt and clay (Haynes, 2005; Gentile et al., 2010). Since SOM plays a key role in water- and nutrient-holding capacity in coarse-textured soils (Wander, 2004; Po et al., 2009; Gregory et al., 2016), continuous organic matter inputs, such as cover crop roots and shoots, may be required to maintain soil function and plant health in raised-bed gardens. Inclusion of cover crops in gardeners' rotations may also promote processes leading to SOM stabilization through increased aggregate formation (Wander et al. 1994, Puget and Drinkwater 2001, Kong and Six 2010).

Ecosystem service provision by winter-kill and over-wintering cover crops
Even across variable soil and light environments, we observed clear differences between cover crops driven by species characteristics, including phenology (seasonal niche and growth period),

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N functional group, and plant architecture. Consistent with other studies, both sampling data and gardeners' observations confirmed that winter-kill cover crops had lower biomass and N fixation and less sustained weed suppression compared to over-wintering cover crops (Schipanski and Drinkwater, 2012; Finney et al., 2016). With their short growth period (~74 days), winter-kill cover crops had little time to accumulate large biomasses or fixed N. On average, field peas provided moderate biomass (3627 kg/ha) and fixed 39 kg N/ha, nearly enough N for a 'light-feeding' vegetable such as radishes. Perhaps because field peas were the slowest cover crop to germinate and cover the soil, they provided relatively poor weed suppression. Oats and oat/pea mixtures provided good fall weed suppression, but oats had the lowest average biomass of any species (1473 kg/ha) and oat/pea mixtures had negligible N fixation (15 kg N/ha on average). Furthermore, rapid decomposition of winter-kill cover crop residue meant that they provided little to no spring weed suppression.

In contrast, all over-wintering species produced high average biomasses (5690 – 12826 kg/ha) and provided nearly complete weed suppression at termination in late spring. Hairy vetch and crimson clover monocultures and rye/vetch mixtures all fixed averages of 190 kg N/ha or more, enough to supply N requirements for 'heavy-feeding' vegetables such as Brassicas and Solanaceous crops. The spring growth period for over-wintering species (~70-75 days) is crucial for biomass production and N fixation (Clark et al., 1997; Teasdale et al., 2004; Benincasa et al., 2010; Cook et al., 2010). Excellent weed suppression by over-wintering cover crops can be attributed to high biomasses and living plant cover through the spring, which prevented weed growth through physical smothering, dense canopies that blocked light, and effective competition for water and nutrients (Creamer et al., 1996; Blum et al., 1997; Isik et al., 2009; Hayden et al., 2014; Finney et al., 2016).

Within the suite of over-wintering cover crops, rye and rye/legume bicultures, with average biomasses over 10,000 kg/ha, were usually most productive. However, in soils with low N availability (< 2.5 g N/kg), crimson clover monocultures produced comparable biomass to rye in many cases. This concurs with other research on annual cover crops showing that over-wintering cereals are usually the most productive monocultures in moderate- to high-fertility soils due to rapid growth rates and strong ability to compete for soil nutrients and water (Karpenstein-Machan and Stuelpnagel, 2000; Sainju et al., 2005; Parr et al., 2011; Finney et al., 2016). Other studies also show that when available soil N is low, legumes may produce equal or greater biomass than cereals (Ranells and Wagger, 1996; Teasdale and Abdul-Baki, 1998; Karpenstein-Machan and Stuelpnagel, 2000; Sainju et al., 2005; Parr et al., 2011; Tosti et al., 2012; Hayden et al., 2014).

Comparing over-wintering monocultures and mixtures, the grass/legume mixtures produced more biomass than the *average* of their component species grown in monocultures, but usually did not yield more than the most *productive* monocultures of rye. This is consistent with other studies on annual cover crops (Ranells and Wagger, 1996; Teasdale and Abdul-Baki, 1998; Karpenstein-Machan and Stuelpnagel, 2000; Parr et al., 2011; Hayden et al., 2014; Finney et al., 2016) and has also been observed in studies of non-domesticated plant communities during the first several years after grassland establishment (Tilman et al., 2001; Hector et al., 2002; Cardinale et al., 2007). In most cases, then, our results suggest that annual grass/legume mixtures may not increase biomass-dependent ecosystem services (e.g., SOM accumulation and N retention), though they may provide a greater range of services than monocultures (Finney et al., 2016). Furthermore, grass/legume mixtures growing in low-fertility soils often produce more biomass compared to grass monocultures (Sainju et al., 2005; Tosti et al., 2012; Hayden et al.,

2014). We found a similar pattern: Rye/vetch mixtures at soil N contents below 2.5 g N/kg usually produced more than the highest-yielding rye monoculture.

We found few differences in average weed suppression between over-wintering treatments; in most cases, grasses, legumes, and bicultures were equally weed-suppressive. This finding contrasts with most previous studies, which generally find that legumes provide less weed suppression than grasses, presumably because the latter compete more effectively for belowground resources (Teasdale and Abdul-Baki, 1998; Hauggaard-Nielsen et al., 2001; Mennan et al., 2009; Isik et al., 2009; Brainard et al., 2011; Hayden et al., 2014). In our study, high seeding rates may have allowed over-wintering legume monocultures – particularly hairy vetch – to suppress weeds by physical smothering and shading (Hayden et al., 2014).

Differences in N fixation between over-wintering treatments were affected by % NDFA and total legume N accumulation, a function of legume biomass and N concentration. Although crimson clover monocultures had greater biomass than hairy vetch monocultures, higher % NDFA and N concentration in hairy vetch monocultures resulted in greater total N fixed. In mixtures with rye, total N fixation by over-wintering legumes depended strongly on legume biomass. Hairy vetch, with its climbing growth habit, produced more biomass in mixture with rye than the low-growing crimson clover. Greater legume biomass, in turn, led to more total N fixation in rye/vetch mixtures compared to rye/crimson clover mixtures.

Species interactions in cover crop mixtures

Previous research has shown that relative to monocultures, certain cover crop mixtures may show greater net primary productivity and provide a broader range of ecosystem services (Creamer et al., 1996; Ranells and Wagger, 1997; Teasdale and Abdul-Baki, 1998; Sainju et al.,

2005; Parr et al., 2011, 2014; Finney et al., 2016). Enhanced performance of mixtures occurs when they are designed to maximize complementary resource use and facilitative interactions while minimizing interspecific competition.

Rye/vetch mixtures combine high biomass with substantial N fixation

Under the conditions of this study, rye/hairy vetch mixtures were the only combination that consistently showed strong complementary and facilitative interactions, as indicated by pLERs greater than or equal to each species' sown proportion and LERs greater than 1. We saw evidence that rye facilitated vetch productivity, partly by providing a stiff, upright trellis for vetch to climb and therefore access more light (Mariotti et al., 2009; Hayden et al., 2014) and better air circulation than in vetch monocultures. Our results concur with other studies documenting facilitative interactions in mixtures of cereals (e.g., rye, barley) with hairy vetch, in which hairy vetch often composes 40-60% of total biomass (Creamer et al., 1996; Ranells and Wagger, 1996, 1997; Teasdale and Abdul-Baki, 1998; Tosti et al., 2012; Hayden et al., 2014; Finney et al., 2016). Taken together, these results suggest that hairy vetch is not usually suppressed by planting in mixture with a cereal.

Our finding that hairy vetch in mixture with rye consistently had lower % NDFA and higher N uptake from the soil compared to vetch monocultures is unusual, and may have resulted from rye stimulating mineralization of labile organic N through a priming effect. In other studies, hairy vetch % NDFA is either similar in monoculture and in mixture with rye, or slightly greater in mixtures (Parr et al., 2011; Brainard et al., 2012; Hayden et al., 2014). Furthermore, mixing legumes with cereals usually decreases legume N uptake relative to monocultures, presumably because faster-growing cereals out-compete legumes for soil N (Jensen, 1996;

Brainard et al., 2012; Schipanski and Drinkwater, 2012; Hayden et al., 2014). In contrast, we found that vetch in mixture with rye usually took up *more* soil N than vetch monocultures grown under similar conditions. Although further research is needed to confirm a mechanism, our data suggest that rye may increase available soil N by 'priming' decomposition of SOM in these soils with very large labile SOM reserves. Priming occurs when organic inputs (including root turnover and exudates from living plants) stimulate soil microbial activity and therefore increase release of mineral N from SOM (Blagodatskaya and Kuzyakov, 2008). Enhanced soil N uptake by vetch in mixture with rye may explain why vetch monocultures tend to have greater % NDFA than rye/vetch mixtures in these gardens. This is consistent with the strong negative correlations between legume N uptake and % NDFA in this study, and with the well-established negative effects of abundant available soil N on % NDFA (Peoples et al., 1995).

Oat/pea and rye/clover mixtures have low legume biomass and N fixation

In contrast to rye/vetch mixtures, both oat/field pea and rye/crimson clover mixtures showed strong competitive interactions that suppressed legume biomass and limited total N fixation relative to monocultures. Compared to legumes, cereals are stronger competitors for below-ground resources due to extensive root development and greater nutrient uptake capacity (Mariotti et al., 2009). Since cereals establish more quickly than legumes and grow taller, they may also out-compete legumes for light (Snapp et al., 2005; Strydhorst et al., 2008). These characteristics may give cereals a strong advantage over slow-germinating legumes (such as field peas) and non-viny legumes (such as crimson clover). Other studies have also found that in mixtures with oats or barley, field peas suffer from rapid depletion of soil water and nutrients, and therefore produce less biomass and fix less N than in monocultures (Jensen, 1996; Hauggaard-Nielsen et al., 2001;

Schipanski and Drinkwater, 2012). In the case of crimson clover mixed with rye, clover's low growth habit likely prevented it from accessing light below tall rye plants (Ranells and Wagger, 1997; Karpenstein-Machan and Stuelpnagel, 2000; Strydhorst et al., 2008; Mariotti et al., 2009; Brainard et al., 2011).

In our study, average % NDFA for field peas and crimson clover tended to be slightly higher in mixtures compared to monocultures, but not significantly so. This is probably due to the severity of competition with grasses and species-environment interactions across the gradient of light and soil fertility. Other research has shown that field peas and red clover can have greater % NDFA in grass/legume mixtures compared to monocultures, and that this is driven by relative grass:legume seeding rates and soil N fertility (Jensen, 1996; Schipanski and Drinkwater, 2012). Our study did not explore the impact of seeding rates on cover crop performance; however, future research could address this issue so that seeding rates can be optimized to reflect environmental conditions in urban community gardens.

Soil fertility effects on N fixation

We found that % NDFA in field pea monocultures was generally low and decreased at high soil N, while crimson clover and hairy vetch monocultures maintained high % NDFA across the full range of soil N (0.7 -13 g N/ kg soil). Many legumes species have adapted to preferentially take up soil N it is available, presumably because nodulation and N fixation carry a high energetic cost to the host plant (Peoples et al., 1995; Clark, 2007). Our findings suggest that this is true for field peas, but not for crimson clover or hairy vetch, despite more than 18-fold variation in soil N contents.

Soil fertility had distinct impacts on mixture biomass composition, and therefore on N

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fixation, for each grass/legume mixture. Both oat/pea and rye/crimson clover mixtures

consistently had less legume biomass and N fixed than their respective legume monocultures, but

soil fertility affected biomass composition differently. In oat/pea mixtures, contrary to our

expectations, increasing soil N *increased* fraction pea biomass and total N fixation. Our results

contrast with those of Jensen (1996), who found that peas composed nearly twice as much of

barley/pea biomass in unfertilized plots compared to those with modest N fertilization. Higher

seeding rates in our study may have intensified competition from the fast-germinating oats and

prevented field peas in low-fertility mixture plots from accessing soil N to support early growth.

In higher-fertility oat/pea plots, additional soil N may have allowed the peas to establish

successfully, compose a greater fraction of mixture biomass, and therefore fix more N than in

lower-fertility plots.

In contrast, increasing soil N availability stimulated vigorous rye growth and thus

suppressed crimson clover biomass and total N fixation in rye/crimson clover mixtures, as other

investigators have also reported (Karpenstein-Machan and Stuelpnagel, 2000; Drinkwater, 2011;

Finney et al., 2016). The marginally significant negative correlation between PC1 and NDFA in

rye/clover mixtures also suggests that competition from rye in fertile soils may have limited

clover's access to resources (e.g., light or non-N soil nutrients) needed to carry out N fixation.

Implications for cover crop selection and management in urban gardens

The large variation in cover crop performance across gardens and species indicates that

management goals, environmental conditions, and cover crop species characteristics all need to

be factored into cover crop selection for urban gardens. Where urban gardeners' priorities

include building SOM and suppressing weeds, and there is no constraint imposed by the need for

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planting vegetables in early spring, an over-wintering cereal such as rye or a rye/vetch mixture is probably the best strategy (Snapp et al., 2005). Rye and rye/legume mixtures were the most productive cover crops in this study, and larger biomass additions generally lead to greater SOM accumulation (Kong et al., 2005; Fornara and Tilman, 2008). High biomass is also associated with good weed suppression (Mohler and Teasdale, 1993; Mirsky et al., 2013; Finney et al., 2016). Though rye alone may provide high biomass and good weed suppression, mixing rye with hairy vetch provides additional benefits, such as N fixation and supply to subsequent food crops, which would not be provided by pure cereal residues with their high C:N ratios (Finney et al., 2016). Given the very high soil N contents we found in some gardens, it may be advisable to plant non-N-fixing cover crops for some years, perhaps introducing limited use of legumes as soil N contents decline and soil C:N ratios increase.

Comparing quantities of N fixed by legumes in Brooklyn gardens with N requirements for vegetable crops confirms that hairy vetch, crimson clover, and rye/hairy vetch mixtures can make substantial contributions to crop N needs (Fig. 2.15). This is particularly relevant for older gardens with lower soil N contents. Further work is needed to understand how legumes and their residues can be managed in urban gardens to synchronize N mineralization with crop N uptake and minimize N losses (Crews and Peoples, 2005; Drinkwater et al., 2008). N supply to crops from decomposing legume residues depends on the C:N ratio of cover crop biomass, timing of termination, residue management, and soil and weather conditions that influence microbial activity (Ranells and Wagger, 1996; Wagger et al., 1998; Clark, 2007; Benincasa et al., 2010; Cook et al., 2010; Campiglia et al., 2014b; Finney et al., 2016). The low C:N ratio of hairy vetch residue makes it vulnerable to rapid decomposition and release of N before crops can take it up (Ranells and Wagger, 1996; Rosecrance et al., 2000). Mixing vetch with a cereal (thus
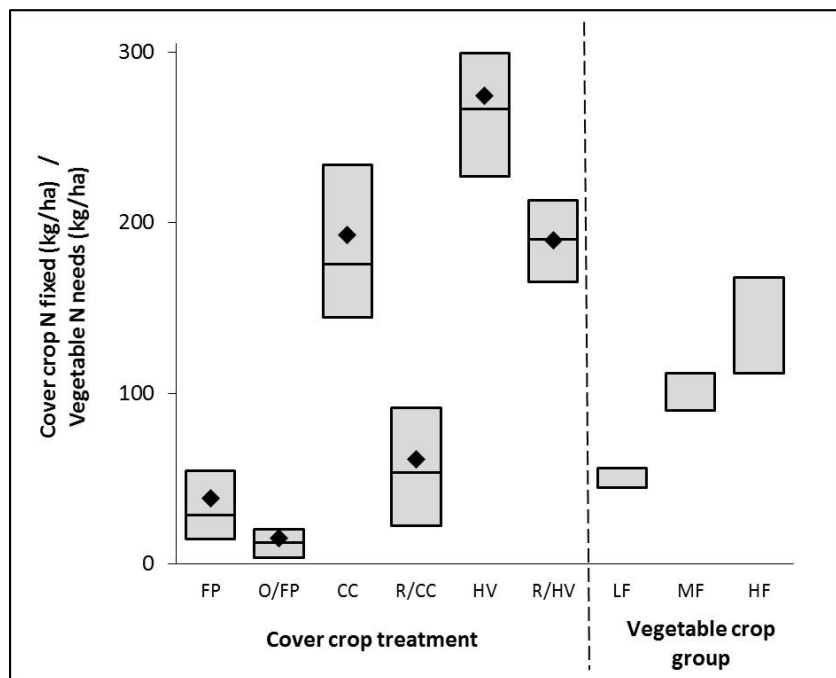
Fig. 2.15. Boxplots of total legume N fixed for cover crops planted in 2012-2013 (left of dotted line), compared to N needs of light-, medium-, and heavy-feeding vegetable crops (right of dotted line). The boxes span the interquartile range (25th – 75th percentile values) for total N fixed by each treatment, with the middle line marking the median and diamonds marking the average. Cover crop abbreviations: FP = field peas, O/FP = oats/field peas, CC = crimson clover, R/CC = rye/crimson clover, HV = hairy vetch, R/HV = rye/hairy vetch. Vegetable crop abbreviations: LF = light feeders (e.g., beans, radishes), MF = medium feeders (e.g., carrots, Cucurbits), HF = heavy feeders (e.g., Brassicas, Solanaceous crops). Vegetable nutrient recommendations are from the Cornell Nutrient Analysis Laboratory.

increasing overall residue C:N) and using no-till management are two strategies that slow vetch decomposition and may better synchronize N release with N uptake by warm-season crops (Parr et al., 2011; Campiglia et al., 2014a). In contrast, previous studies suggest that crimson clover may not supply crop N in the first growing season after cover crop termination, most likely due to its higher C:N ratio and greater cellulose and hemicellulose content compared to hairy vetch, all of which slow decomposition (Ranells and Wagger, 1996; Wagger et al., 1998; Teasdale and Abdul-Baki, 1998; Parr et al., 2011). However, consistent use of legumes can also increase the N stored in SOM, which can be released by microbes in future years for crop use (Drinkwater et al., 2008; Schipanski and Drinkwater, 2011). By building soil N reserves through cover crop

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use, gardeners may be able to supply vegetable crop N needs mainly with N mineralized from legume cover crops and SOM reserves without adding large amounts of compost or synthetic fertilizers.

Facilitating cover crop adoption, evaluation, and innovation by urban gardeners

To realize the potential benefits of cover crops in urban gardens, gardeners need educational and material support, particularly to meet the challenges of managing over-wintering cover crops. Like all agroecological practices, cover cropping requires ecological knowledge and skills for adapting the practice to specific management goals and environmental conditions (Settle, 2000; Shennan, 2008). Selecting cover crops and planning vegetable rotations that include them are two key skills that educators can help gardeners to develop. Understanding the characteristics of different cover crop species and mixtures (e.g., ecological functions, shade tolerance, impacts of soil fertility on cover crop performance) can help gardeners to select appropriate plantings for local conditions.

Gardeners' concerns about over-wintering cover crops delaying spring plantings illustrate that gardeners need support redesigning their rotations to create time and space for cover crops that provide the greatest long-term benefits while also achieving shorter-term goals such as spring vegetable production. After our second year of research, most gardeners felt that using both over-wintering and winter-kill cover crops would provide an acceptable balance. All gardeners agreed that cover cropping requires conscious planning of vegetable crop rotations, and many felt that the rotation planning workshop was one of the most useful (Chapter 3).

We found that gardeners also need tools and equipment to manage high-biomass over-wintering cover crops in the spring. At typical community garden scales (each gardener

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managing up to ~20 m^2), most gardeners felt that hedge shears were a good tool for cutting and mulching the cover crops. In our second year of research, ensuring that each garden had hedge shears and providing training in the cut-and-mulch technique improved most gardeners' experiences managing the over-wintering cover crops. At larger scales, small-scale machinery to mow the cover crops may be necessary. Given that most community gardens have limited funds and secure storage space, developing equipment-sharing agreements with nearby urban farms may be a promising option.

In commercial farming, evaluating multiple outcomes of agricultural practices can improve management decisions as growers become aware of the benefits and tradeoffs associated with each practice (Smith et al., 2011). Using indicators of cover crop performance (e.g., cover, weed suppression, and nodulation) can develop gardeners' knowledge of ecological processes in agriculture and their capacity to improve cover cropping practices. To best facilitate cover crop evaluation and management, field-based indicators should be well-correlated with actual biological performance. In this study, gardeners' observations accurately identified differences between cover crop treatments and sites in terms of cover, biomass composition of cover crop mixtures, and weed suppression, all of which can inform decision-making about future practices.

Further work is needed to develop rapid ways of assessing cover crop biomass and N fixation, however. Even after accounting for ground cover and plant height at sampling, there was still substantial unexplained variation in biomass for all the species we tested. Lack of even rough correspondence between nodule color classes and % NDFA (or N fixed) may simply be the result of insufficient sampling. Due to time constraints and efforts to avoid disturbing the plots prior to biomass sampling, we only examined the roots of two legume plants per plot.

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Furthermore, plants were often dug up from the edges of the plot, where competition for soil N may have been least intense (this was done to leave undisturbed area in the center of each plot for biomass sampling). Had we examined more legume roots from throughout each plot, we may have obtained a better indication of actual N fixation efficiencies. On the other hand, the inner color of nodules may indicate N fixation, but not be well-correlated with quantitative measures of % NDFA. Even if this is the case, we still believe that observing nodule color is a valuable educational experience for gardeners, as it enhanced their understanding of N fixation and the symbiosis between plant and bacteria that enables this process (Chapter 3). However, educators should clarify that the intensity of color in the nodules is not necessarily indicative of the amount of N fixed.

Implications for research needs to support community gardens

Brooklyn's community gardens presented an agricultural research context that was both rewarding and challenging. Conducting research with community gardeners offered tremendous opportunities to address urban gardeners' needs and combine research with education and capacity-building (Chapter 3). As we discovered, distinct environmental conditions and practices in urban gardens may lead to different outcomes for cover crop performance than one would expect based on agricultural field research. These findings underscore our argument that research *for* urban gardens should be done *in* urban gardens to reflect the distinct prevailing environmental conditions and management practices. Furthermore, by integrating our research with gardeners' vegetable planting and harvesting practices, we ensured that recommendations arising from the study would be applicable in these settings. Gardeners also developed their knowledge and skills by participating in designing the study and planting and monitoring cover

crops. Many shared their learning beyond the circle of research participants, inspiring people in other gardens to try cover cropping and instructing them in cover crop selection and best practices (Chapter 3).

The contextual, participatory nature of this work that made it relevant for urban community gardens also posed challenges for measuring cover crop performance and ascertaining the effects of multiple sources of environmental variation. Soil properties and light availability varied widely within and across gardens, along with other environmental variables we were not able to quantify (e.g., air quality). Staggering variation in soil properties, often at fine scales, presented a challenge for accurately measuring legume N fixation. Legume *B*-values – which are used in % NDFA calculations – depend on the rhizobial strains inhabiting legume roots, which vary across soils (Parr et al., 2011). Since it was not feasible to determine separate *B*-values for each plot using their respective rhizobial strains, we relied on literature values for each species. These were likely better reflections of the $\delta^{15}N$ of fixed N in aboveground legume tissue in some plots than in others; as such, our calculations of % NDFA and N fixed should be considered tentative estimates rather than definitive measurements.

Co-variation of environmental characteristics also made it difficult to separate the effects of light and soil properties. Our experience suggests that in future agroecological studies in urban gardens, researchers may need to conduct substantial preliminary fieldwork and lab analyses (e.g., of soil properties) to select appropriate sites for answering the questions of interest. It also suggests a need for non-traditional and participatory research designs that can accommodate variation in environmental characteristics and gardeners' management goals. In this respect, the 'mother and baby trial design' used in research with smallholder farmers may offer a helpful model (Snapp, 2002). This design links a larger, researcher-managed trial

containing within-site replication of all practices with smaller trials of practices chosen by farmers and tested within their cropping systems. That said, such a project requires substantial land for the mother trial (which could be difficult to obtain in densely populated cities) and trained facilitators to assist farmers with setting up trials, monitoring system performance, and documenting farmers' feedback.

Conclusions

As city dwellers seek to grow food and enhance environmental quality through community gardening, public research institutions should support them in developing best practices based on studies in urban agricultural systems. Through participatory research with Brooklyn gardeners, we identified promising cover crop species for improving soil quality and fertility and suppressing weeds in urban gardens.

Comparing cover crop treatments with respect to ecosystem services showed that over-wintering cover crops have greater biomass production, weed suppression, and total N fixation than winter-kill cover crops. On average, field peas provided modest biomass and enough fixed N to supply a light-feeding vegetable, but germinated slowly and therefore gave poor weed suppression. Oats and oat/pea mixtures had acceptable fall weed suppression, but had low biomass and negligible N fixation in oat/pea mixtures. In contrast, rye and rye/legume mixtures, with average aboveground biomasses of over 10,000 kg/ha, were the most productive treatments. While rye/legume bicultures did not usually out-produce rye, mixtures with an even biomass composition – such as the rye/hairy vetch mixtures in this study – may provide a greater range of ecosystem services (e.g., N retention by grasses and N fixation by legumes). In soils with low N contents and low weed pressure, crimson clover monocultures may produce comparable biomass

to rye while adding fixed N. All over-wintering cover crops, including legume monocultures, provided excellent weed suppression at cover crop termination in most cases. Gardeners' observations indicated that no-till mulches from these cover crops provided substantial weed control throughout the subsequent growing season. Hairy vetch and crimson clover monocultures and rye/hairy vetch mixtures also fixed averages of 190 kg N/ha or more, enough to supply the needs of heavy-feeding vegetable crops (e.g., Brassicas, Solanaceous crops).

Out of the three grass/legume mixtures we studied, rye/hairy vetch bicultures showed the greatest evidence of complementary resource use and facilitative interactions. The ability of hairy vetch to 'climb' rye to access more light in mixtures may have improved biomass productivity in rye/vetch mixtures compared to the component monocultures. Surprisingly, compared to vetch monocultures, planting vetch in mixture with rye significantly increased legume soil N uptake (possibly due to priming of SOM decomposition by rye root exudates) and decreased legume % NDFA. However, since vetch maintained high biomass production, total N fixation in rye/vetch mixtures was the greatest of any mixture and usually provided sufficient N for a heavy-feeding vegetable crop. In contrast to rye/vetch mixtures, competitive interactions in rye/crimson clover and oat/field pea mixtures suppressed legume biomass and therefore reduced the amount of N fixed. Slow germination and establishment of field peas and the low growth habit of crimson clover may account for poor performance of these legumes in mixture with fast-growing grasses.

Both light availability and soil fertility impacted cover crop performance in urban gardens. Light availability was positively correlated with total biomass of field peas, oat/pea mixtures, and rye/hairy vetch mixtures. Biomass production in crimson clover and rye monocultures was not affected by light availability and remained high even in shaded conditions.

Soil fertility affected N fixation directly in field pea monocultures by decreasing % NDFA, and indirectly in oat/pea and rye/crimson clover mixtures through its effects on biomass composition. Contrary to our expectations, increasing soil N increased fraction legume biomass and total N fixed in oat/pea mixtures. Higher soil N contents may have alleviated the negative effects of competition from densely planted oats for soil N on early growth of field peas. In contrast, for rye/crimson clover mixtures, increasing soil N availability stimulated vigorous rye growth and therefore suppressed crimson clover biomass and total N fixed. Soil fertility did not impact N fixation in crimson clover or hairy vetch monocultures, both of which maintained high % NDFA across a wide range of soil N contents.

To realize the potential benefits of cover cropping in urban gardens, garden educators should: 1) develop gardeners' knowledge of cover crop species' ecology 2) help gardeners design vegetable rotations that include cover crops, and 3) facilitate access to tools and/or small machinery for cutting down over-wintering cover crops. Future research and education efforts might also refine field-based indicators that gardeners can use to evaluate cover crop contributions to soil protection and improvement, weed suppression, and N fixation. Such support and monitoring tools can help gardeners implement and refine cover cropping practices for their local conditions to achieve goals for vegetable production and environmental stewardship.

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CHAPTER 3

DESIGNING PARTICIPATORY RESEARCH FOR SCIENTIFIC, EDUCATIONAL, AND

COMMUNITY BENEFITS: A CASE STUDY OF COVER CROP RESEARCH WITH

BROOKLYN GARDENERS

This chapter will be condensed for submission to a multidisciplinary agricultural journal.

Megan M. Gregory • Scott J. Peters

Abstract

Participatory agricultural research may develop knowledge, skills, and communities of practice

that support ecologically-based management of farms and gardens. However, little research has

addressed specific practices to facilitate social learning for sustainable agriculture, or the

possibilities and challenges of participatory action research (PAR) in an urban gardening context.

Through a case study of a two-year PAR project on cover crops I facilitated with urban gardeners

in Brooklyn, NY, I address the questions: How can PAR be designed in an urban community

gardening context to achieve positive outcomes for science, education, and communities? What

are the challenges, and how might facilitators address them? Several practices contributed to

scientific, educational, environmental, and social benefits in our project. A collaborative

research design process -- including group decision-making regarding priority management goals

and seasonal niches for cover cropping – shaped the research to address gardeners' needs and

include workable practices. Co-interpretation of emerging results during visits to participating

gardens tapped gardeners' local knowledge to improve our cover cropping practices. Engaging

gardeners in monitoring cover crop plantings using checklists of agroecological indicators

strengthened their knowledge of ecological processes (e.g., nitrogen fixation, weed suppression) and adaptive management skills (e.g., systematic observation, applying monitoring knowledge to improve practice). Facilitating opportunities for participants to share their knowledge with others (e.g., field days) supported leadership development. Sustained, in-person support enabled gardeners to implement cover cropping practices with environmental and social benefits, such as improved vegetable harvests with little or no synthetic fertilizers. Finally, PAR strengthened the urban gardening community of practice by providing opportunities for FFS gardeners to share gardening knowledge, practices, and resources, and by inspiring adoption of cover cropping beyond FFS gardens as participants modeled the practice and instructed others. Challenges included: addressing community-defined goals and priorities within the constraints of a discipline-specific dissertation project; structuring participation to tap the educational potential of engagement in multiple stages of the research process, while limiting participants' time commitment to a feasible level; providing sufficient one-on-one research and education support with limited funding for community-based partners; and designing accessible record-keeping forms and processes. Despite its challenges, PAR in urban gardening contexts may develop knowledge and skills that support improved stewardship practices and community capacity to work toward environmental and social goals. To inspire and sustain more participatory research partnerships, I recommend 1) Strengthening institutional support for PAR, through a) structures that invite community-defined questions and match community organizations with faculty committed to long-term research partnerships and b) integrating research ethics and cultural competency training into curricula and professional development, and 2) Funding and professional development support for permanent community researcher/educator positions based within local Cooperative Extension offices and/or community-based organizations.

Keywords

adaptive management, agricultural extension, community gardens, communities of practice, cover crops, engaged scholarship, Farmer Field Schools, ecological knowledge, gardening education, outcomes monitoring, participation, participatory action research, public participation in scientific research, public scholarship, social learning, urban environmental stewardship

A Note on Voice, Roles, and Authorship

Since this paper is written in the first person yet has two authors, words of explanation are in order. I (Megan) chose to write in the first person to clarify my roles in shaping both gardeners' experiences of participatory action research (PAR) and their reflections on those experiences, as interpreted in this paper. As the facilitator of the PAR project that is the focus of this case study, interviewer of individual gardeners, and facilitator of group evaluation sessions, my values, hopes, background, and interests certainly shaped the 'case' under study and the conclusions reported in this paper. Writing in the first person aided me – and I hope will aid the reader -- in critical reflection on how my worldview influenced, and was influenced by, my relationships with fellow gardeners and the PAR process we undertook together. Such transparency is particularly important in establishing authenticity and trustworthiness in research with a narrative orientation, such as that reported here (Pinnegar and Daynes, 2007: 11-15, 20-21).

That said, my co-author (Scott) provided essential guidance in research design, instruction and mentoring in qualitative data collection techniques (e.g., writing field notes and conducting interviews), and input in data analysis and drawing lessons for practice. Regular conversations with Scott throughout my fieldwork provided a fresh perspective on the process, outcomes, challenges, and possibilities of participatory research and helped me to shape my

work with gardeners to further develop those possibilities. His appreciative, yet critical, feedback on initial drafts also helped me to clarify the type and degree of evidence for various conclusions and place this work in the larger context of public scholarship. Therefore, while I accept full responsibility for errors or weaknesses in this analysis, any valuable insights into the practice and possibilities of participatory research with urban gardeners belong as much to him as to me; hence, our shared authorship of this paper. -- *MMG*

Introduction

What happens when you take an inquiry-based approach to agricultural research and education developed in the rice fields of rural Indonesia, and apply it with urban gardeners growing vegetables, herbs, flowers, and community on patches of land wedged between apartment buildings and bustling city streets? In this paper, I explore precisely this situation by analyzing the outcomes, challenges, and lessons learned from a participatory research project I initiated and facilitated with community gardeners in Brooklyn, NY, guided by principles of the Farmer Field School (FFS) methodology (van den Berg and Jiggins, 2007; Braun and Duveskog, 2008; Sherwood, 2009). Urban community gardeners across North America make important contributions to food access and nutrition, stewardship of urban green space, and social well-being in their neighborhoods (Saldivar-Tanaka and Krasny, 2004; Alaimo et al., 2008; Draper and Freedman, 2010; Gittleman et al., 2012; Gregory et al., 2016). However, they also face challenges for agricultural production and sustainable management of natural resources. In addition to the social and institutional challenges of securing land tenure, material and financial resources, staff and volunteer commitment, and technical assistance (Pfeiffer et al., 2014; Drake and Lawson, 2015; Cohen and Reynolds, 2015), the urban growing environment and typical

practices pose unique constraints for growing food sustainably. In NYC, these difficulties include: poor soil quality in raised-bed 'constructed' soils, unbalanced nutrient management, and severe weed and insect pest pressures (Gregory et al., 2016).

Developing gardening practices based on principles of agroecology may alleviate some of these challenges, thus enhancing community gardens' contributions to urban food production and access while preserving environmental quality. Agroecological management involves implementing suites of practices that enhance biological processes supporting crop production and environmental quality (e.g., internal nutrient cycling, biological control of insect pests) and minimize use of external inputs (Kanyama-Phiri et al., 2008; Shennan, 2008). In diverse farming systems, agroecological approaches show promise for improving soil quality, nutrient cycling, and weed and insect pest management (Liebman and Dyck, 1993; Landis et al., 2000; Drinkwater et al., 2008; IAASTD, 2009; McDaniel et al., 2014; Schipanski et al., 2016). An important question, then, is how to facilitate learning that enables urban gardeners and their partners (including researchers and educators) to develop, implement, and refine agroecological practices.

In sharing and reflecting on my story of participatory agroecological research with Brooklyn gardeners, I hope to offer inspiration and guidance for engaged scientists and community educators who partner with gardeners to develop sustainable practices *and* gardeners' capacities to use them successfully and share them with others. Specifically, through this case study I address the following research questions:

- How can participatory action research (PAR) be designed and facilitated in an urban community gardening context to achieve positive outcomes for science, education, and communities?

- What are the challenges of doing PAR with urban community gardeners, and how might facilitators address them?

I first place my work with Brooklyn gardeners in the context of agricultural extension efforts directed toward building farmers' and gardeners' capacities for ecologically-based management. From the literature on these extension efforts, I identify three crucial factors that support agroecological management: ecological knowledge, adaptive management skills, and communities of practice where farmers can reflect on and refine their practices in dialogue with others. Given that inquiry-based extension approaches have proven valuable for nurturing such knowledge, skills, and social connections, I then review traditions of participatory agricultural research and situate them in the scholarship on public participation in scientific research more broadly. I outline emerging understandings of how the design of participatory research projects -- in particular, the degree and quality of public participation – may influence outcomes. Having laid out this conceptual framework, I explain my interest in applying one model of participatory agricultural research, the Farmer Field School (FFS), in an urban community gardening context and learning from that process.

In the Methods and Results sections, I present a case study of cover crop research with Brooklyn gardeners, through which I explore how participatory research with urban gardeners can be designed to produce positive outcomes for science, education, and communities, and how its challenges might be addressed. Finally, in the Discussion section, I interpret experiences in the Brooklyn FFS in the context of diverse literatures on participation and learning in agricultural and natural resource management research. Using this case and others, I develop recommendations for how scientists, community educators, and institutions (e.g., colleges,

universities, funders) might better support community-led efforts toward healthier and more sustainable neighborhoods through research collaborations with urban gardeners and other community-based stewards of natural resources.

Foundations for practicing agroecology

Agroecological management holds promise for sustaining ecosystems and people, but it is complex. It is site-specific (that is, appropriate practices depend on the ecological and social context) and knowledge-intensive with respect to local environmental conditions, ecological relationships and processes, and how an agricultural system responds to different practices (Röling and Jiggins, 1998; Shennan, 2008). As such, successfully practicing agroecology requires ecological knowledge and adaptive management skills. *Ecological knowledge* refers to an understanding of the abiotic and biotic components of agricultural ecosystems, as well as the ecological processes supporting food production and maintenance of environmental quality (Shennan, 2008; Gregory et al., 2016). Knowledge of the traits and ecological niches of species in a cropping system can inform decisions about practices to achieve management goals – for example, which cover crops will fix nitrogen that can become available to subsequent vegetable crops as cover crop residues decompose. *Adaptive management* involves continually monitoring and evaluating management practices and modifying them to achieve desired outcomes for people and the environment (Peterson, 2005; Fernandez-Gimenez et al., 2008). Adaptive management is essential for developing agricultural practices tailored to local conditions (e.g., differing levels of soil fertility or light availability), and for building agricultural systems that are resilient to a changing climate and environment (Kroma, 2006; van den Berg and Jiggins, 2007; Braun and Duveskog, 2008).

In addition to ecological knowledge and adaptive management skills, *communities of practice* play crucial roles in inspiring and supporting agroecological practice (Fisk et al., 1998; Buck, 2002; Kroma, 2006; Warner, 2007; van den Berg and Jiggins, 2007; Barthel et al., 2010). Generally speaking, communities of practice are groups of people who share an interest or craft (for example, urban gardening) and enhance their individual and collective capacities through regular interaction (Wenger, 2006). Communities of practice provide a context for social learning, defined as changes in understanding that occur through participatory processes and result in a shared system of concepts, practices, and values which, in turn, enables participants to manage their agricultural systems sustainably (Woodhill and Röling, 1998; Kroma, 2006; Warner, 2007; Reed et al., 2010). Learning occurs over time through activities such on-farm experimentation and observation, discussion and reflection on the outcomes of different practices, and field days. Social learning *may* contribute to improved stewardship of (agro)ecosystems and/or action to transform social institutions to better support sustainable agriculture and natural resource management (Pence and Grieshop, 2001; Buck, 2002; Kroma, 2006; Warner, 2007; van den Berg and Jiggins, 2007; Braun and Duveskog, 2008; Bonney et al., 2009; Berkes, 2009). However, economic and sociopolitical inequities (e.g., immediate livelihood concerns of the poorest community members, unequal access to and influence with policymakers, unfavorable policies for adoption of agroecological practices) can constrain or halt individual and institutional adaptation in response to social learning (van den Berg and Jiggins, 2007; Berkes, 2009; Ballard and Belsky, 2010). Therefore, when considering how to promote agricultural practices that integrate goals for food production, community health, and environmental quality, it is important to consider institutional and policy contexts in addition to facilitation practices at the local group level (Fisk et al., 1998; Röling and Jiggins, 1998).

Education for agroecology through participatory action research (PAR)

Scholars and practitioners of agriculture and natural resource management show growing interest in public participation in scientific research for its potential to generate and strengthen knowledge, skills and communities of practice that enable ecologically-based management (Warner, 2007; Fernandez-Gimenez et al., 2008; Bonney et al., 2009; Berkes, 2009; Ballard and Belsky, 2010; Shirk et al., 2012). A specific form of public participation in scientific research, Participatory Action Research (PAR) involves collaboration between members of a community and researchers to address practical problems in a specific local context, with goals of education and informing action to bring about a more just and sustainable situation (Greenwood and Levin, 2007). Broad community participation in research, advocates of PAR argue, may generate knowledge that is relevant to practice, strengthen and contextualize research by incorporating multiple perspectives, and build community capacity to continue engaging in inquiry and action that advances individual and collective well-being (Pretty, 1995; Fischer, 2000; Mordock and Krasny, 2001; Vasquez et al., 2006; Fernandez-Gimenez et al., 2008; Berkes, 2009).

One agricultural extension approach that exhibits characteristics of PAR and has shown promise for supporting agroecological management is the Farmer Field School (FFS) methodology. A FFS is a collaborative, inquiry-based learning process in which groups of farmers experiment with new practices, apply agroecosystem analysis to evaluate their impacts, and incorporate this information into management decisions to achieve goals for crop production, environmental quality and community health (van den Berg and Jiggins, 2007; Braun and Duveskog, 2008; Sherwood, 2009). As described by these authors, well-designed FFSs include several common principles:

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- **Participatory, discovery-based learning:** Farmers participate in defining research questions that are important in their situation and selecting practices to test in comparative trial plots.

- **Agroecosystem analysis:** Participants observe, evaluate, and compare different practices by recording their effects on multiple ecological processes, such as crop growth and yield, pest and beneficial insect populations, soil conditions, etc.

- **Social organization:** FFSs participants exchange ideas based on diverse life experiences, make decisions collectively, and form relationships that allow them to continue addressing agricultural and community needs after the conclusion of formal FFS activities.

The FFS methodology was developed in response to an urgent need to educate smallholder farmers in Indonesia in integrated pest management as pesticide-resistant strains of rice pests emerged and the human health impacts of insecticide over-use became clear (Oka, 1997; Braun and Duveskog, 2008). Rather than providing narrow technical training, the FFS approach promotes ecological knowledge and problem-solving skills, thus building farmer capacity to respond to diverse management challenges in their cropping systems and local environments (van den Berg and Jiggins, 2007). Since their origin in the late 1980's, FFSs have been conducted on topics ranging from soil fertility management to food security and nutrition (Braun and Duveskog, 2008).

Critical reviews of FFS impact studies show that this experiential group learning process consistently promotes agroecological knowledge, observation-based management, and increased productivity among participating farmers. By enabling farmers to manage biological processes

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for increased crop health and productivity, FFSs have substantially decreased pesticide use in smallholder farming systems throughout Asia, where the majority of impact studies have been conducted (van den Berg and Jiggins, 2007; Braun and Duveskog, 2008). With support for post-FFS activities, additional positive outcomes include enhanced farmer capacity to answer research questions through experimentation, form or strengthen farmer associations to address livelihood goals, and share knowledge with others (van den Berg and Jiggins, 2007; Braun and Duveskog, 2008). However, FFSs may suffer from weaknesses, including: their time-intensive nature which makes participation more difficult for vulnerable individuals, failure to foster co-learning due to poor facilitation skills and/or lack of commitment to participatory processes by influential stakeholders, and insufficient support for post-FFS activities (Braun and Duveskog, 2008; Sherwood, 2009). In particular, exclusion of farmers from key stages of the research process (e.g., defining the content of the field school, managing learning plots, or conducting agroecosystem analysis) limits their opportunities to develop adaptive management skills such as critical thinking, experimental design, observation, and analysis (Schut and Sherwood, 2007; Sherwood, 2009). Nonetheless, where farmers have engaged meaningfully in a group research process -- from defining the questions to testing practices and monitoring agroecological outcomes -- agricultural extension approaches based on participatory research show promise for catalyzing agroecological management.

PAR: Designing for multiple benefits

The importance of research processes for achieving educational goals in FFSs invites careful consideration of how participatory agricultural research can be designed to support desired outcomes. Scholars of PPSR suggest that project outcomes relate to the *degree* and *quality* of

public participation (Bonney et al., 2009; Shirk et al., 2012). *Degree of participation* refers to "the extent to which individuals are involved in the process of scientific research: from asking a research question through analyzing data and disseminating results." *Quality of participation* refers to "the extent to which a project's goals and activities align with, respond to, and are relevant to the needs and interests of public participants" (Shirk et al., 2012) (p. 29). Quality encompasses social and relational aspects of collaborative research, such as trust, credibility, fairness, and mutual respect and openness to learning between scientist and practitioner participants, as well as between various interest groups (Kapoor, 2001; Cornwall, 2008; Shirk et al., 2012).

Different design choices affect the potential for positive outcomes for science, education, and communities – the broad categories of outcomes that facilitators and participants in environmentally-focused PPSR projects often strive for in order to have a meaningful impact (Shirk et al., 2012).[9] For example, projects that engage practitioners (e.g., farmers, natural resource managers) in defining project goals and selecting practices to test have shown promise for producing scientific knowledge that can be applied in the field to improve environmental sustainability (Pence and Grieshop, 2001; Warner, 2007; Ballard and Belsky, 2010). The greatest potential for educational and community-level outcomes (e.g., improved practices and/or policy) also seems to lie in those projects where practitioners are involved not only in data collection, but in multiple stages of the research, from defining (or refining) goals and research questions, establishing treatments, analyzing and interpreting results, and drawing conclusions

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[9] Shirk et al. (2012) use the terms *science*, *individuals*, and *social-ecological systems* to categorize project outcomes. I use the terms *science*, *education*, and *communities*, respectively, to refer to roughly the same categories. Briefly, outcomes for science include new research findings and knowledge. Education includes developmental outcomes such as building new knowledge, skills, and identities. Finally, outcomes for communities refer to changes in broader environmental and social conditions that Shirk et al. (2012) categorize as outcomes for *social-ecological systems*. These would include stewardship practices that enhance ecosystem services.

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for practice (Fernandez-Gimenez et al., 2008; Bonney et al., 2009).

While all participatory research projects should strive for high-*quality* public participation, no *degree* of public participation is inherently 'better' than another. Although a greater degree of participation may offer more opportunities for learning and affecting community-level change, it is also important to consider public participants' time and interest in engaging in the research process (Cornwall, 2008; Krasny et al., 2014). Deep engagement in the process of research can be time-consuming for participants, which may limit its feasibility in certain contexts (Shirk et al., 2012). However, it is important to be aware of the implications of different project designs for potential outcomes.

PAR in urban gardening education: Knowledge gaps and challenges

In considering how PAR approaches like FFSs might be designed to promote positive outcomes for science, education, and communities in an urban gardening context, at least two challenges present themselves. First, little research has addressed specific *project design choices and practices to facilitate social learning* for supporting sustainable agriculture and natural resource management (Woodhill and Röling, 1998: 68; Reed et al., 2010). Where evaluation of learning outcomes from participatory research occurs, it often relies on pre/post assessments, and may not provide insight into the specific experiences (among many experiences during the research process) that contributed to learning. Second, little research has explored the *possibilities and challenges of PAR in urban community gardens* that includes *collaboration between gardeners, local organizations, and scientists based at colleges and universities*.

Understanding the dynamics of community-research partnerships in urban agriculture and environmental stewardship is important, given that practitioners have expressed a need for

technical assistance in horticultural practices and desire to partner with scientists to monitor and improve their practices (Krasny et al., 2014; Silva and Krasny, 2014; Cohen and Reynolds, 2015). Despite this, experiences in urban environmental stewardship indicate that researchers, educators, and gardeners may face challenges in forming participatory research groups, designing inquiry-based agricultural education programs, and evaluating their impacts. From a practical standpoint, investing the time to form and maintain strong research partnerships in community gardening contexts may be challenging for all involved given the modest (read: under-staffed) support infrastructure of grassroots garden groups and the small non-profits and government agencies that support them (Krasny and Tidball, 2009; Silva and Krasny, 2014). From a project design standpoint, there are few examples of protocols to engage volunteer stewards in monitoring ecosystem services resulting from their efforts and using that information to adapt their practices (Krasny et al., 2014). Furthermore, there is limited knowledge of educational outcomes in current community garden programming, or of linkages between educational outcomes for individuals and community-level environmental and social benefits (Krasny and Tidball, 2009; Krasny et al., 2009). As such, educators have a limited knowledge base to inform program development for specific goals.

University-based agricultural scientists also face challenges for engaging in genuinely participatory research, particularly sharing decision-making power with lay participants and devoting substantial time to building relationships and facilitating group learning processes. In an institutional environment where the dominant culture, norms and reward systems privilege generalizable knowledge over locally adapted practices, and scientific publications over patient processes of community education, many researchers and Extension specialists struggle to invest time and energy in participatory research partnerships for sustainable agriculture. Furthermore,

those that do often encounter skepticism from colleagues regarding the value of such activities (Pence and Grieshop, 2001; Kroma, 2006; Armstrong et al., 2015).

In summary, participatory agricultural research holds promise for developing agroecological practices that address constraints faced by urban gardeners and for nurturing gardeners' knowledge and skills to refine and share sustainable practices. However, there has been little empirical research to guide the design of inquiry-based community gardening education. Furthermore, there are few examples of extended collaborations in which urban gardeners and scientists partnered to pursue integrated goals for science, education, and environmental and community well-being. A better understanding of how PAR design affects project outcomes in urban gardening contexts, and how all stakeholders navigate its challenges, could inspire and guide much-needed PAR efforts in community gardening education and practice.

Methods

PAR project and case study overview

In this paper, I explore the experiences of urban gardeners and community educators, and my own experiences as the researcher-facilitator, in an agroecological PAR project modelled on the FFS methodology. Motivated by an ethical commitment to participatory and mutually beneficial research partnerships as well as interest in exploring the process and potential of PAR, I worked with gardeners in Brooklyn, NY to research the ecosystem services of cover crops in urban gardens. Cover crops are close-growing plants sown in rotation with food crops or between food crops to cover bare ground. Before planting the next food crop, cover crops are cut down and the shoots are either left as a mulch on the soil surface or incorporated into the soil. Cover cropping

may provide ecosystem services for agriculture, including improved soil quality from organic matter additions and root growth, nitrogen fixation by legumes, nutrient recycling, weed suppression, and habitat for beneficial insects (Snapp et al., 2005; Tonitto et al., 2006; Clark, 2007; Drinkwater et al., 2008). As such, cover cropping may increase vegetable yields while decreasing reliance on external inputs such as synthetic fertilizers (Abdul-Baki et al., 2002).

Our agricultural research goals were to identify cover crops with potential for enhancing soil quality, weed suppression, and nitrogen fixation in urban gardens, and to learn how variation in soil properties and light availability impact cover crop growth (so as to tailor recommendations for different sites). The methods and results of this investigation are reported elsewhere (Chapter 2). Throughout the process, I used a variety of methods to document, evaluate, and enhance program design and the resulting scientific findings, gardener learning, and environmental and social outcomes. In this paper, I analyze these materials as a case study to address research questions regarding how PAR can be designed in an urban gardening context to integrate positive outcomes for science, education, and communities, what challenges facilitators and their gardener partners may encounter, and how these might be addressed effectively. While facilitating the FFS and sharing emerging interpretations of the data for this case study, I developed and refined a set of study propositions which I used to guide further data analysis (Yin, 2008). The final version of these propositions is provided in Appendix A.

Forming neighborhood-based PAR groups

In the Spring of 2011, I partnered with local organizations (Cornell University Cooperative Extension- New York City [CUCE-NYC] and East New York Farms! [ENYF!]) to form PAR groups in Bedford-Stuyvesant and East New York, Brooklyn. I had met (and interviewed)

gardeners and local organization partners from both neighborhoods the previous year while conducting a separate, broader survey of the agroecological and social characteristics of community gardens throughout NYC (Chapter 1; Gregory et al., 2016). Of the many unique and vibrant community gardens I visited throughout the city, those of Bedford-Stuyvesant and East New York offered ideal opportunities for partnering with gardeners to conduct PAR on cover crops and soil management. Most importantly, community gardeners in both neighborhoods showed strong interest in learning more about practices to improve soil quality to support intensive vegetable production in an environmentally sustainable way. These gardeners make important contributions to food access and nutrition by growing vegetables for their families and neighborhoods, so maintaining (and improving!) soil quality is of particular interest to them. In addition, gardens in these areas are 'clustered' close enough to facilitate shared workshops, and I found local organizations eager to help connect me with gardeners and inform project design and implementation.

Each PAR group included a staff member from the local organization sponsor (CUCE-NYC and ENYF!), 'community educator partners', and a group of gardeners from nearby community gardens. Community educator partners were participating gardeners who received training and small stipends to assist with workshop scheduling and reminders, curriculum development, and co-facilitating cover crop monitoring workshops. Each PAR group had one community educator partner in 2011-2012 and two community educator partners in 2012-2013. Since additional gardens and gardeners joined the project in our second year, this increased the need for assistance coordinating and co-facilitating planting and monitoring workshops.

With the help of staff from local organizations and garden leaders I had met through my previous survey of NYC gardens, in the Spring of 2011 and 2012 I organized interest meetings

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for what became known as the 'Brooklyn Farmer Field School.' I also promoted the project through personal invitations and – with the permission of local organization staff and garden leaders -- at garden meetings, workdays, workshops, and other community events. Interested gardeners received flyers outlining the types of management challenges cover crops could address, a tentative schedule of workshops and research activities (with specific locations and times to be determined among the group), expectations of participants in terms of planting and maintaining research plots, benefits to participating gardeners, and contact information for myself and the collaborating local organization staff member. Benefits to gardeners offered through the project included: learning about cover cropping practices to improve soil health and provide other benefits (e.g., weed control), opportunities to attend optional workshops on topics of the group's choosing, receiving free soil tests and cover crop seed, and strengthening connections with other gardeners and gardens.

Over the Brooklyn FFS's two years, approximately sixty gardeners from 17 gardens participated in the project by attending workshops and planting and monitoring cover crop research plots, with guidance from me and community educator partners. Many other gardeners joined us for some workshops and planted cover crops, often invited and instructed by FFS participants. Like community gardeners in general, the PAR groups were diverse in many ways, bringing together people of different racial/ethnic groups, genders, stages of life (working, parenting, retired, etc.), gardening experience, and educational backgrounds. In Bedford-Stuyvesant, approximately two-thirds of participating gardeners were Black/African-American and 20% were White, with the remainder composed of Latino/as and one gardener from the Caribbean. The vast majority of gardeners in this group (~85%) were born in the United States, with just a few born and raised in Puerto Rico or Grenada before coming to the United States. In

East New York, nearly half of the FFS gardeners were Caribbean-American, having emigrated from their birthplaces in Barbados, Guyana, Jamaica, St. Lucia, St. Martin, and Trinidad. About one-third of gardeners in the East New York FFS were Black/African-American, with the remainder Latino/a and White. Both groups were approximately three-quarters female and one-quarter male. Two-thirds of participating gardeners were working, while about one-third were retired. Gardeners' levels of experience varied widely, from first-time gardeners to people with life-long farming or gardening experience. Many gardeners in East New York had grown up farming in the Caribbean or the American South and therefore had extensive farming experience, though they were continually adapting this knowledge to the distinct climate and growing conditions they encountered in Brooklyn (Shava et al., 2010). FFS gardeners were similarly diverse in terms of formal education: some gardeners had not had the opportunity to complete high school, others had completed high school and/or college, and a few held Masters' degrees. What brought the groups together was participants' shared passion for community gardening and their desire to learn more about sustainable practices for growing food in the city.

PAR Activities

With these two groups of community educators and gardeners, I adapted the FFS methodology to conduct participatory research on cover crops over two field seasons (2011-2012 and 2012-2013). Through a series of garden-based workshops, I engaged gardeners in refining goals and research questions, designing field experiments, planting and monitoring cover crops, and sharing initial findings through field days (Table 1). The overall program design involved large-group workshops (including all gardeners in each neighborhood group) and small-group research activities in each garden. Large-group gatherings included workshops to define priority

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Table 1. Stages of the research process during the FFS research project on cover crops and corresponding PAR activities. There were two cycles of cover crop research (2011-2012 and 2012-2013). CUCE-NYC = Cornell University Cooperative Extension – New York City; ENYF! = East New York Farms!

Stages of the research process	PAR Activities
Forming partnerships	• Summer 2010: MMG conducted initial fieldwork, including interviewing gardeners about practices and challenges; conducting ecological sampling (e.g., land-use maps, soil sampling, insect scouting), and forming partnerships with local organizations. • Winter 2010 – Spring 2011: MMG worked with CUCE-NYC and ENYF! staff to develop initial ideas for the FFS and hold interest meetings with gardeners.
Research design	• Spring 2011 & 2012: During planning workshops each spring, FFS gardeners selected priority management goals for cover cropping and seasonal niches of cover crops to test. • Summer 2011 & 2012: Based on gardeners' priority goals for cover cropping and existing literature, MMG selected cover crops to test and indicators of cover crop performance to measure (in consultation with Laurie Drinkwater of the Cornell University Department of Horticulture). • Summer 2011 & 2012: FFS gardeners selected cover crop treatments for their plots, with guidance from MMG to choose 'best bet' cover crops for their vegetable rotations and management goals.
Establishing field experiments	• Late Summer – Fall 2011 & 2012: FFS gardeners planted cover crop research plots using standard seeding rates and planting practices, with guidance and materials provided by the MMG and paid community educator partners.
Data collection	• Fall 2011/Spring 2012 & Fall 2012/Spring 2013: During cover crop monitoring workshops each fall and the following spring, FFS gardeners recorded observations of cover crop performance for each plot on checklists prior to sampling (Appendix B). • Fall 2011/Spring 2012 & Fall 2012/Spring 2013: MMG collected information on soil properties and light for each plot each fall, and quantitative sampling data on cover crop performance each fall and the following spring. • Summer 2012 & 2013: In mid-summer following cover crop termination and establishment of vegetable plots, MMG conducted a survey of FFS gardeners to learn their perspectives on cover crop management and perceived impacts of the cover crops.
Data analysis & interpretation; Drawing conclusions	• Fall 2011 & 2012: MMG compiled preliminary monitoring and sampling results, then presented and discussed them with gardeners at Fall Wrap-Up meetings each year. Gardeners brainstormed explanations for differences in cover crop performance among treatments and sites, suggested improvements in species selection and planting practices, and discussed how the results could inform cover crop selection for their gardens. • Fall 2013 – Summer 2015: MMG completed soil and plant sample processing and analyses in the lab, compiled all monitoring and sampling data, conducted statistical analyses, and wrote dissertation and report for gardeners putting findings in the context of the cover crop literature.
Sharing findings	• Spring 2012 & 2013: FFS gardeners planned and hosted field days each spring (before cutting down cover crops) to share their learning with other gardeners. • Summer 2015: Following completion of lab work, MMG shared complete findings and recommendations for soil and cover crop management with gardeners through a Cover Crop Research Update (presentation & discussion), written report, and individualized soil test reports accompanied by an interpretation guide.

management goals and select cover crop combinations to test, and fall wrap-up meetings to discuss preliminary results and participate in program evaluation. In response to gardener interest, I also offered large-group workshops on rotation planning, soil testing and management, and cover crop residue management in partnership with local organization partners. Hands-on research activities in each garden included selecting cover crop treatments for each plot, planting cover crops, and monitoring their growth and performance. Table 1 provides further details of gardener participation in each stage of the research.

Case Study Methodology

To address research questions regarding the design, outcomes, and challenges of PAR in an urban gardening context, I conducted a case study of the Brooklyn FFS with guidance from my co-author in research design, data analysis, and interpretation. Incorporating multiple sources of evidence, case studies are well-suited for studying complex and context-specific processes and for tracing operational links between events (for example, between program design choices, participant experiences, and outcomes) (Yin, 2008: 8-11, 18). I chose an embedded, single case study design (Yin, 2008: 47-53), in which the main unit of analysis is the overall PAR project with Brooklyn gardeners. I also consider two levels of embedded units of analysis: the neighborhood-based PAR groups, and the experiences of participating individuals. Larger program design considerations and outcomes are represented by my field notes, follow-up surveys with gardeners about cover crop management and perceived impacts, and documentation such as workshop outlines and resources developed for urban gardeners and educators. Transcripts of group evaluation sessions represent the collective experiences of the two PAR groups, while transcripts of one-on-one, semi-structured interviews provide insight into the

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experiences of participating individuals.

Data Collection

This case study comprises five types of data. First, I used my field notes to provide context on the workshop series and research activities in gardens. Based on participant-observation, my field notes provide detailed narrative accounts of PAR project design and implementation and my initial impressions of potential outcomes. I paid special attention to gardeners' and educators' responses and contributions to PAR activities, including expressions of enthusiasm and learning, as well as frustration and confusion. Since the field notes also detail informal interactions not directly related to PAR activities (e.g., conversations before and after workshops) they provide insight into the relational aspects of PAR that are central to project quality (Shirk et al., 2012).

At several points throughout the FFS, I conducted semi-structured interviews with seven participating gardeners. These conversations explored individuals' hopes for the FFS, efforts to make space in their lives for an intensive PAR project, learning through the FFS, how they had or planned to apply this learning, meaning and significance of FFS experiences in terms of their goals for themselves and their communities, and suggestions for improving the project to better support those goals. I selected interviewees who showed consistent participation in the FFS program and who represented a range of gardening backgrounds and life experiences. The group of interviewees included first-time gardeners as well as participants with extensive gardening or farming experiences. Some interviewees were born in the United States, while others immigrated from Puerto Rico or the Caribbean islands before becoming involved with community gardens in Brooklyn. All interviews were recorded, transcribed for analysis, and

verified for accuracy with the original recordings.

I also conducted four group evaluation sessions (one with each FFS group in each of the study's two years). Held in late fall following cover crop planting and fall monitoring activities, these sessions included a presentation and discussion of preliminary results and a group evaluation activity of the FFS experience. I solicited gardeners' feedback in four areas: cover crops and practices, workshop scheduling and logistics, how well the program promoted gardening knowledge and skills, and the value and drawbacks of garden-based research (particularly as compared to typical single-session workshops). Each theme was written on a poster, where I asked participants to post short written comments of "pluses" (positive aspects) and "changes" (things that could be improved in future programs) with respect to each theme. We used these comments as a starting point for group discussions of each theme, which I facilitated and, with the permission of all participants, tape-recorded and transcribed. Therefore, data for the case study include both the brief written comments and transcripts of group discussions.

In mid-summer 2012 and 2013, after gardeners had cut down over-wintering cover crops and established vegetable crops for the season, I conducted a follow-up survey with participating gardeners. This involved brief conversations with each gardener regarding their perspectives on cover crop management and perceived impacts of the cover crops on soil, weeds, and subsequent vegetable crops. In addition to providing information on the cover crops and practices used to manage them (Chapter 2), these conversations shed light on gardeners' experiences incorporating knowledge from PAR into their practices, and on potential outcomes for vegetable production and ecosystem services in their gardens.

Finally, in my analysis I drew on numerous documents that reflect project design and

products. These include: my workshop outlines, workshop products (e.g., gardeners' completed monitoring datasheets for each cover crop plot, posters with gardeners' initial evaluations of each cover crop treatment), presentations of preliminary and final cover crop research results, and resources for gardeners and educators based on results from the PAR project.

<u>Data Analysis</u>

I conducted data analysis in multiple cycles during and after the PAR project in conversation with my co-author, who provided a fresh perspective on possibilities for creating educational and community-building opportunities within the FFS and learning from this work. Frequent synthesis and reflection on available data (e.g., field notes) with my co-author helped me to enhance the program as I came to better understand gardeners' hopes, goals, and experiences in the FFS. Ongoing data analysis also allowed me to use an iterative process of developing and refining theoretical propositions (Appendix A) (Yin, 2008: 130-131), using several cycles of the steps outlined below:

Thematic (content) analysis: First, I read and synthesized field notes, transcripts of individual interviews and group evaluation sessions, follow-up survey results, and documents as they were produced. During this process, I used thematic (content) analysis to identify passages relevant to my research questions and major analytic categories (Creswell, 2009). These included: gardeners' motivations and goals for engaging in PAR; outcomes for science, education, and communities (Shirk et al., 2012), links between program activities and outcomes, and challenges and solutions in garden-based PAR. When identifying themes from field notes and interviews (both of which contain narrative data), I considered all stories intact, preserving the sequence and detail of each account even as I interpreted participants' experiences in light of

a common analytical framework (Dodge et al., 2005; Riessman, 2008).

Explanation-building: As I identified outcomes and challenges of PAR in this urban gardening context, I employed explanation-building (Yin, 2008: 141-144) to develop and refine propositions of how particular outcomes occurred or how particular challenges might be addressed (Appendix A), testing and refining these propositions in conversation with my co-author. Consistent with the logic of case studies, we used an interpretive approach to explanation (Lin, 1998; Dodge et al., 2005), seeking not to predict outcomes based on inputs across diverse contexts, but rather to understand *how* program design choices and participant experiences contributed to specific outcomes *in this case*, and even for particular individuals. This involved drawing on my long-term engagement with the FFS groups (and the larger community of urban gardeners in which they participate) and varied sources of 'rich data' (e.g., narrative field notes, interview transcripts) (Lincoln and Guba, 1985: 301; Maxwell, 2005: 110). Detailed narrative descriptions, in which participants connected particular experiences to particular outcomes, provided initial evidence for causal links specified in the study propositions (Dodge et al., 2005). I then refined propositions by comparing them against further data as it became available, revising or qualifying the propositions to reflect additional details of this PAR project (Yin, 2008). To further strengthen the validity of findings, I ensured that each proposition was supported by multiple sources of evidence (i.e., triangulation) (Lincoln and Guba, 1985: 309-313; Dodge et al., 2005: 295; Yin, 2008: 115-116; Creswell, 2009: 191).

Searching for discrepant or qualifying evidence: After all data collection was complete and initial propositions developed, I conducted another reading of field notes, interviews, and group evaluation session transcripts. In this reading, I actively searched the data for evidence that would refute or qualify my initial interpretations. This technique may counter

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confirmation bias (Maxwell, 2005: 108) and contribute to a more nuanced understanding of a case by attending to all the data.

Drawing lessons for practice: The final step in data analysis involved interpreting the data to draw lessons for educational practice (Creswell, 2009). To suggest promising directions for PAR design and support in community gardening contexts, I synthesized findings from this study with diverse literatures on participation and learning in agriculture and natural resource management and refined tentative conclusions and recommendations in discussion with my coauthor. My experiences working in community education, particularly with Cooperative Extension, also informed my interpretation of this study and its lessons for research and education practice.[10]

As my final conclusions took shape, I prepared a brief summary and invited gardener interviewees and participants in group evaluations sessions to offer feedback (Lincoln and Guba, 1985: 314; Yin, 2008: 182-184; Creswell, 2009: 191). I asked them to share whether or not the conclusions matched their experience (and how), if they would qualify or change any findings, and if there were other important lessons they would include. The responses I received lent further support to the conclusions reported in this paper and summarized in Appendix A. In particular, both gardener and local organization staff perspectives highlighted that sustained, in-person support from scientist facilitators of PAR may foster educational benefits for participants and improved stewardship practices (see below, 'Results: Outcomes for Communities: Stewardship practices').

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[10] After completing field work for this study but before finishing data analysis and writing, I (Megan) began work as a community gardening educator with Forsyth County Cooperative Extension in Winston-Salem, NC. My experiences there stimulated further reflection on the potential and challenges of participatory research from the perspective of a locally-based organization with a broad mission and multiple programs designed to build local leaders' knowledge and skills in community organizing, sustainable horticulture, health promotion, and environmental stewardship.

Results

My synthesis of case study data from the Brooklyn FFS suggests that participatory research in urban gardening education can have a number of positive outcomes, including:

- Scientific findings (new knowledge) that are relevant to gardeners' practice and strengthened by local knowledge;

- Educational outcomes for participating gardeners, including ecological knowledge, adaptive management skills, and leadership development; and

- Community-level outcomes, including improved stewardship practices and ecosystem services within gardens, and potentially strengthened communities of practice within and among urban gardeners.

In the sections that follow, I use case study data to illustrate these outcomes and link them to project design considerations and facilitation practices that may have contributed to them. I then outline challenges for PAR in this case.

Outcomes for Science

My experience working with gardeners in Brooklyn indicates that the PAR process may enhance the relevance of research to practice and strengthen research findings with practical, local knowledge. As recounted in field notes and group evaluation sessions, these outcomes resulted from a combination of structured, deliberative processes to facilitate gardener participation in research design, as well as conversations during regular visits to the gardens where we worked, particularly for cover crop monitoring workshops.

<u>Relevant research</u>

Engaging gardeners in designing our research made it more applicable to their needs, and ensured that the cover cropping practices tested were compatible with their vegetable crop rotations. Although the research focus on cover crops was determined prior to formation of PAR groups,[11] gardeners helped develop specific research questions by selecting priority management goals and cover crops to test. During initial planning meetings in the spring of 2011, I facilitated a garden diagramming activity for FFS participants to identify areas for management improvements in their plots. Each FFS group then compiled lists, from which emerged gardeners' top priorities of (1) improving soil quality and fertility, and (2) suppressing weeds. These priorities guided our specific research questions, cover crop choices, and the indicators of cover crop performance that we measured.

Gardener participation in research design also helped us (that is, me, together with staff and community educator partners and gardener participants) to choose seasonal niches of cover crop species to test and planting methods. In our first year of research, gardener input led to a focus on over-wintering cover crops, which are planted later in the growing season (September – October), survive the winter, and grow through early spring before being cut and mulched prior to planting the next crop of vegetables. I also encouraged 'under-seeding' – planting cover crops beneath and between standing food crops. This was to address gardeners' concerns to reap a fall harvest of vegetables, as I noted after the second set of planning workshops:

> "Talking about the crops gardeners have planted brought out the importance of a fall harvest as something we need to consider when choosing cover crops... I made a mental note to focus on cover crops that are either very winter-hardy and can be planted in the

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[11] This was due to the constraints of a discipline-specific dissertation project and the need to apply for funding well in advance of conducting research. However, the choice of cover cropping as a topic for in-depth experiments was informed by a prior season of research in NYC, in which soil quality emerged as one of gardeners' top concerns (Gregory et al., 2016).

late fall, or can be successfully established under-seeded into standing food crops" (Field notes, 12/July/2011)

Gardeners later commented on how this made recommendations arising from the research applicable in their gardens. Reflecting on the most useful cover crops and practices that he learned during the FFS in a group evaluation session, one gardener noted:

> "Being able to sow [cover crops] with eggplants that are still in the ground, was really an insight and helpful. It will make me more likely to do it in the future."

In our second field season, soliciting gardener input during spring meetings led us to broaden our suite of cover crops to include winter-kill species. These are cool-season annuals (e.g., oats, *Avena sativa*, and field peas, *Pisum sativum*) that are planted in late August and grow until the first killing frost. They form a dead mulch that protects the soil over the winter, and allow gardeners to plant vegetable crops in early spring. In contrast, the over-wintering cover crops – while excellent for soil improvement – preclude March and April plantings of vegetables because these cover crops grow through mid-May before being cut down in preparation for summer vegetables. Despite my instructions to plan on summer vegetables following the over-wintering cover crops planted in 2011, the need to delay planting in cover-cropped plots frustrated some gardeners in the spring of 2012. Recognizing this limitation of over-wintering cover crops sparked interest in exploring winter-kill cover crops during the 2012-2013 season:

> "Gardeners quickly agreed that they were definitely interested in trying out some winter-kill cover crops, like oats and peas, this year. 'By August our summer crops are already established and we can seed around them,' said [gardener], 'and this way I could still do early spring crops next year.'" (Field notes, 20/March/2012)

By adding field peas and oat/pea mixtures to our research, I sought to address gardeners' interest in having information on cover crops that would allow them to plant early spring crops in some

beds. During follow-up surveys after the second complete year of research, many gardeners

noted that they planned to use a combination of over-wintering and winter-kill cover crops,

rotating among beds each year. This, they felt, would allow them to achieve substantial soil

quality, nitrogen fixation, and weed suppression benefits in beds with over-wintering cover

crops, while also having spaces for early spring plantings each year where winter-kill cover

crops had been planted (Chapter 2).

Interpretation and practice informed by local knowledge

Not only did gardeners help define relevant research questions and workable cover crop options

to test, they also informed our interpretation of research results with their knowledge of local

environmental conditions and suggested improvements in planting practices. When the winter

wheat (*Triticum aestivum*) cover crop failed to establish in the fall of 2011, gardeners were the

first to recognize that seed predation by birds was the problem. As I visited gardens to take

cover measurements and facilitate monitoring workshops several weeks after our first plantings,

gardeners pointed out that they had seen birds pecking for seeds in the research plots. Some

gardeners noted that they also had to protect certain vegetable crops from birds (for example,

covering lettuce with netting or row cover). One participant (an urban farm manager) suggested

that we cover newly planted seed with row cover until the plants became established. He offered

what was left of a roll of row cover at the farm for use at sites that were hit particularly hard in

2011, and this organization budgeted for several rolls of row cover to cut and distribute to

gardens participating in the cover crop study the following year. In 2012, we covered all newly

planted seed with row cover, which greatly improved cover crop establishment (Fig. 1). As this

story shows, gardeners' knowledge of local environmental conditions and previous experiences

gardening in Brooklyn proved invaluable in identifying why certain cover crops failed to establish. They also proposed a practical solution, which informed subsequent planting efforts and extension materials on cover cropping practices for urban gardeners.
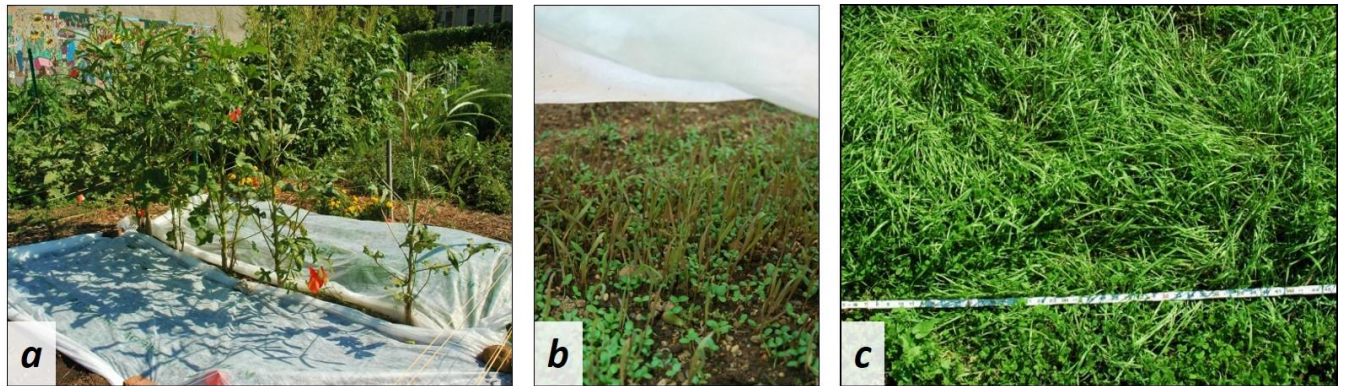
Fig. 1. Innovation in cover crop planting practice suggested by an FFS gardener: Protecting newly planted plots with row cover to prevent seed predation by birds. Informed by years of experience gardening in Brooklyn, a participant in the FFS suggested an effective solution to seed predation by birds: protecting newly planted plots with row cover until cover crop seeds germinated. a) Row cover over newly planted cover crop seed in a community garden, Fall 2012. b) Cover crop seed germinating under row cover. c) Well-established rye (*Secale cereale*)/crimson clover (*Trifolium incarnatum*) mixture, three weeks after planting.

Thus, gardener participation in studying cover cropping practices through the FFS enhanced scientific outcomes in at least two ways. First, facilitating their input in defining priority management goals and selecting cover crop species to test ensured that the research would address their challenges and provide information about practices they can integrate into their vegetable crop rotations (albeit with extra planning compared to rotations without cover crops). As such, I believe that the research will provide a basis for informed decisions about future management practices. Second, by visiting the gardens regularly and evaluating cover crop plots with gardeners, I tapped their local knowledge to understand the results of initial plantings and improve our practice.

Outcomes for Education

My case study data suggest that participatory research offers a generative context for individual and social learning around urban gardening. Through interviews and group evaluation sessions, gardeners shared how they gained knowledge of ecological processes, adaptive management skills, and, in some cases, new confidence in their abilities to serve as a leader or educator for other gardeners. My field notes and workshop products provide further evidence for development of gardeners' knowledge, skills, and leadership capacities through participatory research.

Ecological knowledge and adaptive management skills

Through their participation in cover crop research, gardeners learned about ecological processes that underlie cover cropping as a management strategy (e.g., soil quality improvement through organic matter additions, nitrogen fixation, and weed suppression), and the potential benefits of these processes in their gardens. In group evaluation sessions and interviews, many gardeners spoke of the monitoring activities[12] – in which they observed and recorded observations of cover crop growth, legume nodulation, weed suppression, and so forth – as crucial to developing their understanding of ecological processes and observation skills. For example, several gardeners noted how looking for nodule number and color[13] on the roots of legumes helped them understand the importance of nitrogen fixation in supporting a healthy vegetable crop in future

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[12] See Appendix B for an example checklist for monitoring over-wintering cover crops (adapted from versions used during the FFS).

[13] Nodules are "bumps" on the roots of legume plants, which house nitrogen-fixing bacteria in the genus *Rhizobia* (Fig. 2b). These bacteria capture nitrogen gas from the atmosphere and convert it into a form that the plant can use. When a legume cover crop is mulched or incorporated into the soil before the next planting of vegetables, some fixed nitrogen is released for crop use, and some is stored in soil organic matter. A pink or red color inside the nodules signifies that the *Rhizobia* bacteria are actively fixing nitrogen, so this was one of the indicators of cover crop performance gardeners observed.

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seasons (Fig. 2):

> "Watching the nodules, pulling them out and looking at them for the color, the white, the pink, the size… I thought that was very interesting, because I didn't even know that was important, how the dirt needs to have nitrogen in it. And I'm like, 'What?! That's amazing!'"

> "I was sort of… oh! *Elated*! … When we were seeing if [the crimson clover] had the nodules… when you[14] *come back* now, and you measure, and you looked at everything, and you say, 'Well, OK, we're going see if there's any fixation in the thing,' and we started looking at the nodules... And you said, '[FFS gardener], what do you see?' I said, 'Well, give me that one, let me see.' I said, 'Look one here! This is only pink. And this one is red red red…' And oh! I said, 'Well, OK, it's catching, it's coming!' … So I was really excited. And I'm looking forward now, that I'll be having a better crop for next year."

> "I had heard about cover crop, but I didn't understand what a cover crop was all about. So by planting the cover crop, pulling it up and looking at the nodules, that was really exciting, because you show us pictures, but the pictures don't do justice as when you actually do it yourself in your garden, and you pull it up… It's going to help my soil, get the nutrients back in it, that it's lacking… because believe it or not, I've been planting since '86 and I never did cover crop in my area. But I notice my vegetables was getting smaller and smaller 'till you was explaining that those vegetables – tomatoes, cucumbers, peppers, even the corn – is stripping the soil from all the nutrients, but I wasn't putting anything back in it. So, now I know that every year, I need to do cover crop in order to keep my soil enriched."

Gardeners also learned about weed suppression by cover crops during the monitoring workshops, in which we compared weeds in control plots (where no cover crops were planted) and cover-cropped plots. One gardener noted,

> "[A]fter we planted the crimson clover, when we measure, it was practically no weeds there. But where we didn't have [cover crops] – the control area, you called it – the weeds that it had! So, I see the importance now of the cover crop. Like I said, I heard about it. I had seeds. But I never planted because I didn't know what was it. But being educated now on it, it's a great thing, because I realize it control a lot of the weeds."

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[14] In all quotations from gardener interviews and group evaluations sessions, 'you' refers to the first author, who was the interviewer as well as facilitator of FFS workshops and research activities.

Fig. 2. a) Gardeners at the Powell St. Garden in Brooklyn, NY examine the roots of a crimson clover cover crop to check for nodules (the bumps on legume roots where nitrogen-fixing bacteria live) as part of cover crop monitoring activities in Spring 2013. b) Close-up of nodules on crimson clover roots with a pink color indicating active nitrogen fixation (see Note 13, previous page).

These quotations highlight how gardeners learned about ecological processes by actively observing them in their own gardens. Importantly, they demonstrate a solid understanding of the connections between their observations of the cover crops (e.g., a pink or red color inside the nodules on legume roots) and their agroecological function (e.g., adding nitrogen to the soil via plant residues, which enhances vegetable production in the next season). Finally, their accounts evince enthusiasm and excitement in discovering, understanding, and nurturing ecological processes for more productive and sustainable gardens.

Gardeners also spoke of the monitoring activities as giving them tools and skills for the adaptive management process of trying new practices, then monitoring and reflecting on the outcomes to inform future practices. For example, in a group evaluation session, one gardener remarked how participating in cover crop research cultivated a habit of observation and analysis. As background, he gardened in soil with unusually high nitrogen fertility and severe weed

pressure. As a result – unlike in most gardens -- the legume monocultures in his plots

(particularly crimson clover, *Trifolium incarnatum*) were not very competitive with weeds. In

contrast, rye (*Secale cereale*), which competes more strongly for soil nitrogen, did suppress weed

growth. During the evaluation session, this gardener wrote that a positive aspect of the FFS was

that the "project actually requires me to do work, pay attention to weeds in my plot – forcing me

to be attentive!" As gardeners discussed the experience of participating in a research project, he

expanded on this comment:

> "I learned how to do [cover cropping]. So it's very holistic in that I'm learning my
> timing of what I grow changes. Now I'm looking at, 'Oh, what type of weeds do I have?'
> Because I thought that whole plot [a crimson clover cover crop plot observed during
> monitoring activities] was crimson clover. And it turns out that crop is like, 60% clover
> and 40% chickweed. So I just went walking by and I'm like, 'Oh, it looks good.' And
> you're like, 'No, no, look closer.' And I'm like, 'That's not what I want.' So now I'm
> doing much better management, stewardship practices, much more focused on it in terms
> of, 'How do I kill weeds now so they don't come up in the spring?' So I'm learning
> practices to have – maybe upfront have more labor so I don't have to exert tons of hours
> of weeding in the Spring."

Other gardeners also valued the process of making and recording systematic observations about

the cover crops as a lasting learning experience, as this gardener expressed:

> "As opposed to other workshops, you go and you listen, and you do have a tendency to
> forget. But this… will stay with us... planting the cover crops in your garden, looking at
> it, staying in tune with it, watching the plants grow, writing it down, making a log of
> everything… it's more like an experiment. But we learned a lot from that… Because you
> had to come back, to take a look at the crops, and then make a note of what you see."

My experiences facilitating the monitoring workshops indicate that gardeners drew on

their observations and evaluations of the cover crops to improve their management practices – a

key skill for adaptive management. For example, in 2011, gardeners who had difficulty

establishing a cover crop beneath crowded vegetable crops suggested that the following year

they would consider wider spacing of food crops, both to enhance crop health and to permit

under-sowing of cover crops. Another gardener noticed how chickweed (*Stellaria media*, a cool-season annual weed) re-grew vigorously amid the earlier-planted crimson clover, while plots of hairy vetch (*Vicia villosa*) -- which is more cold-tolerant and therefore planted later in the fall -- had few weeds the following spring. He suggested that for chickweed-infested beds, it might be best to time cover crop planting later in the season to give the chickweed less time to re-establish after cultivating the soil. By linking their observations of problems to suggestions for improvements, gardeners demonstrated their ability to adjust practices to achieve desired agroecological outcomes, such as vigorous cover crop growth for soil protection and improvement or weed suppression.

While many gardeners enjoyed the monitoring activities and found them worthwhile learning experiences, a few participants felt that they were too time-consuming. For example, at the group evaluation session after our second season of research, one gardener wrote,

> "I'm not so interested in doing the research and completing the sheets [cover crop monitoring checklists]; More interested in results."

This comment indicates a limitation of participatory research: it takes time and can be tedious, and therefore may not be attractive to all potential participants. I discuss this issue further below ('Discussion: Challenges of PAR'). However, this gardeners' comment does not change the conclusion that monitoring and reflecting on the outcomes of different gardening techniques may foster learning that supports improved practices; it simply indicates that not all gardeners will have the time or interest to engage in monitoring. I should also note that the number of positive comments about the monitoring workshops and the research process far outweighed the number of negative comments: After the second year of research, 14 of the written comments posted at group evaluation sessions related to monitoring workshops and participating in long-term

research. Only two of these comments were negative: the comment above, and another which simply said "Time." Twelve comments were positive, emphasizing learning that occurred through monitoring, the discovery and excitement of hands-on activities observing the cover crops, gains in practical skills for using cover crops, and the opportunity to build relationships with a researcher. For example, participants placed these comments as "pluses" of involving gardeners in research:

> "I think long-term research projects are more fruitful than one-day workshops. I learned a LOT – very helpful with many aspects of gardening."

> "Researcher really hearing the needs of the specific gardeners and gardens – Relationship to gardeners and gardens developed over time."

Thus, through the FFS, gardeners learned about the ecological processes behind cover cropping and developed adaptive management skills for refining this practice to fit their rotations, management goals, and garden sites. Gardeners' reflections on their experiences in interviews and group evaluation sessions suggest that engaging gardeners in monitoring the outcomes of their plantings using agroecosystem analysis and simple checklists (Appendix B) facilitated many of these educational outcomes, though a few gardeners felt this was too time-consuming.

Leadership development

In addition to building knowledge and skills relevant to their own gardening practice, many FFS gardeners also developed new identities as educators and leaders by sharing their learning with others (Fig. 3). For a number of gardeners, this was an important motivation for engaging in the project. When I asked gardeners why they decided to take part in the FFS during interviews,

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Fig. 3. Sign on a community garden shed promoting cover crop use and offering assistance from FFS gardeners. Enthused by their new knowledge of cover crops and skills gained from planting research plots, FFS participants promoted the practice to other gardeners who couldn't commit to the full research project. I (MMG, the PAR facilitator) noticed this sign when I stopped by the garden to take cover measurements several weeks after planting cover crops. Many (non-FFS) gardeners at this garden cover-cropped a portion of their plots with guidance from FFS participants and extra seed provided through our research project.

many expressed a desire to learn *specifically* to share their new knowledge with others. For example, one gardener decided to participate in order to share greater knowledge of gardening with the children in her neighborhood, and so contribute to community nutrition and health:

> "When [local organization staff member] told me about the Farmer Field School, I thought it was interestin' for me to learn more… and by learning more, it would be beneficial to the garden… My thing was, if I get the kids involved in the gardening, I know a little bit. But the more educated I get on gardening, I could *pass it along* to the children… and they will pass on, and hopefully, by our next generation, we'll have a healthier generation. We'll have *less* obesity. We'll have *less* hypertension."

She goes on to share how she had already begun to do this as part of an after-school program that engages youth in market gardening to improve access to fresh foods in the community:

> "I explain it to the kids, and they're excited because they want to know, 'What was that little stuff growin' up?' … [In October,] the community kids came in to help clean up the weeds… And so I point out the beds with the cover crop and I said, '*Those* you don't pull up!' 'So why we can't pull up, ain't it weeds?' And I said, 'No, it's not weeds. It's cover crop!' So I explained to them what cover crop was, to the best of my ability. The purpose of the cover crop, which it serve *greatly*, as eliminating weeds, and the nutrients that it put back in the soil, that you have a healthier and more productive crop for the next

year. So they was very interested to see, when you cut open the nodules come the spring time, how inside gonna look."

This gardener felt that educating children and youth on ways to produce a healthy crop could, in time, help increase access to fresh foods, improve nutrition, and thus improve community health. Participating in collaborative research on cover crops supported this goal by enhancing her own understanding of practices to enhance soil health and crop production, and providing a field demonstration that she could use as a site for education.

In a similar way, another gardener related how participating in cover crop research helped her share her concern for practicing environmental stewardship with her family. She began by expressing her interest in learning how to enhance soil quality and crop production, but then she connects this to a desire to educate her children about caring for the Earth and growing healthful food:

> "I really want to learn how to grow things, and how to connect with Mother Earth… [What sounded interesting about the FFS was] learning about the dirt and how we can help it be *better* for our plants. I thought that was very interesting, because I always thought dirt was dirt… And I didn't know that you can change it for the betterment of your growing of the plants. So, I was like, 'That's interesting, I think I want to learn that.' …
>
> Overall, I want to be able to look at my garden, and look at things that are… growing in a healthy way… I just want to be able to look at my garden and say, 'Okay, so I grew these tomatoes, I grew these cucumbers,' and take them home to my family, and then *they* could see what we're capable of doing. And that we don't always have to go to the supermarket, because it not only saves money, it teaches the children a lot about the Earth, and the connection, and eating healthy. So it's, it's a lot more to it than just growing a tomato, or a cucumber, or a squash."

Reflecting on her experience as part of the FFS, this gardener goes on to show how sharing her new knowledge of using cover crops to improve soil fertility provided a point of connection with her son:

"My son loves science. So I would go home and explain to him [about nitrogen fixation in the nodules], and he would see the science side of it. And he'd say, 'Oh, Mom, that's interesting! I'm gonna go tell my science teacher and see what she thinks about that.' Because they're studying the different elements, and nitrogen is one of them. So it's all connecting to him; it's connecting to me… So I explained to him what we were doing, and he'd come out and see the cover crops. And so he thought that was great. And I bring my nieces also. So, they're getting the idea."

For the two gardeners quoted above, learning about cover cropping connected to broader values and hopes for their communities – such as community health through improved access to fresh vegetables, and environmental awareness and concern. As they shared their new knowledge of cover cropping, they further developed their identities as educators and leaders in creating positive social and environmental change.

While gardeners shared what they learned with others on their own, after hearing these stories (both in interviews conducted between the first year's plantings and cover crop maturity the following spring), it occurred to me that I could support gardeners' desires to share their new knowledge by encouraging them to be educators in their neighborhoods. Therefore, each spring I worked with several garden groups as they organized events to show the cover crops to other neighborhood gardeners, explain how and why they planted them, and introduce children to soil science concepts and nitrogen fixation with hands-on demonstrations. The experience of planning and leading a field day helped develop gardeners' skills and confidence as educators, as this description in my field notes illustrates:

"[FFS gardener] invited guests to introduce themselves and their gardens, then led them to her plots to explain our work – the cover crop combinations we were trying out, their potential benefits, and the process of planting, defending the seeds from our avian foes, and plans for mulching the cover crops before planting vegetables this spring. She explained how she had inherited pretty poor soil and was hoping that the organic matter from the cover crops would improve it, make it easier to work and better at holding water. She also recounted her struggle with weeds during her first season, and pointed out how there were fewer weeds among the cover crops compared to her control plot, then choked with shepherd's purse, horsetail, and goosegrass…

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[W]hat I remember most clearly about the field day was a sense of quiet pride as I took a back seat, watching [FFS gardeners] share their experiences with the other gardeners… Especially [FFS gardener], who was so timid and quiet in our initial Farmer Field School meetings, unsure of herself because she was new to gardening – it was wonderful to see her teaching and sharing. I knew she hadn't lost her sense of being a 'new' gardener, or her openness to learning and trying new things. But I'm glad that as she starts her second season, she feels that she has something to share as well as many things to learn." (Field notes, 14/April/2012).

These stories illustrate that when a PAR project connects to participants' hopes for their communities and generates knowledge that contributes to realizing those hopes (even in very small ways), many are eager to take on roles as educators and leaders as they share their learning with others. Facilitating opportunities for participants to develop their skills and confidence as educators, such as organizing and leading field days, may further support leadership development and knowledge-sharing.

Outcomes for Communities (environmental and social impact)

I have explored how PAR with Brooklyn gardeners generated practice-relevant science and ecological knowledge, adaptive management skills, and leadership abilities among participating gardeners. But did new knowledge of sustainable practices and gardeners' new capacities contribute to positive outcomes at the community level? In this section, I explore some potential environmental and social outcomes of the FFS in Brooklyn. However, I first acknowledge that in comparison to outcomes for science and education, the outcomes of PAR for communities are more difficult to assess in this case (and probably most cases). With regard to tangible potential outcomes related to garden productivity and sustainability, gardeners' goal of building soil quality and fertility is a long-term goal. It will take more than one or two seasons of cover cropping to have a substantial effect on soil properties, although some short-term effects on soil

tilth and moisture may be observed more quickly. Furthermore, given the multiplicity of factors

influencing crop health and productivity (e.g., varieties, weather, pests) it will always be difficult

to precisely identify the effects, if any, of cover crops on subsequent vegetable harvests.

Outcomes of participatory research for broader social goals may be even more difficult to

ascertain, given the informal nature of most knowledge-sharing that occurs in the urban

gardening community.

Keeping in mind these words of caution, I note initial signs that the Brooklyn FFS may

contribute to community outcomes. Perhaps the most visible outcome thus far is the

implementation of improved stewardship practices (i.e., cover cropping). Based on follow-up

interviews with gardeners and results of the cover crop research itself, I believe these practices

can provide ecosystem services that enhance food production on a sustainable basis. Field notes

and group evaluation sessions also revealed that FFS gardeners' learning and leadership

capacities may facilitate broader dissemination of new knowledge about sustainable practices,

thus strengthening the urban gardening community of practice.

Stewardship practices

In addition to developing knowledge and skills, participants in agriculturally-focused PAR

projects will likely implement stewardship practices with environmental and agricultural

benefits. The research I conducted with gardeners in Brooklyn indicates that many cover crops

planted as part of the FFS provided substantial ecosystem services. In most cases the over-

wintering cover crops provided nearly complete soil cover, high biomass (plant material, which

contributes to soil organic matter), excellent spring weed suppression, and enough fixed nitrogen

to supply a heavy-feeding vegetable crop such as tomatoes (Chapter 2). Follow-up surveys with

gardeners confirmed that most participants observed sustained weed suppression and improvements in soil moisture and tilth following over-wintering cover crops. About three-fourths of participants also felt that legume cover crops contributed to crop nutrition, noting that the cover crops decreased or eliminated the need for inputs like commercial fertilizers while vegetable harvests remained high (Chapter 2). When I asked one gardener if and how the FFS may have helped her address gardening challenges during an interview, she commented,

> "At the garden, the biggest challenge was the weeds taking over… I didn't want to put anything harsh in the garden, so I didn't want to use a spray. So I would physically go out there and pull them, and I would be sore the next day because I'm not used to being out there in the garden, 'cause I work in an office! So that's how I used to deal with it. But now that I see we can do cover crops, and that will help with the weed situation. That is a huge, a huge learning experience for me. And it will make life much easier, from what I'm seeing so far."

Thus, both quantitative measurements and my follow-up conversations with gardeners indicate that cover cropping may enhance soil quality and vegetable harvests in urban gardens while decreasing the need for environmentally damaging inputs such as synthetic fertilizer, as well as time spent weeding.

Several lines of evidence in this case study suggest that sustained, in-person support in choosing, planting, and managing cover crops as part of the research provided encouragement and guidance that helped gardeners to implement cover cropping successfully. It may seem obvious that gardeners would plant cover crops as part of a research project on cover crops. However, I believe this is important because, as staff members based at the sponsoring local organizations noted, people don't necessarily feel confident enough to implement new practices in their gardens simply by attending a workshop or demonstration at another location. Both my field notes and gardeners' comments during evaluation sessions illustrate how in-person, garden-by-garden support was important for gardeners planting cover crops for the first time. After the

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first round of planting workshops, I wrote,

> "[A lesson] that came out of the planting workshops was the importance of… working with gardeners to choose a cover crop that fits their specific vegetable planting schedule, gardening goals, and garden site… 'I got seeds from [another organization] before, but I never planted them because I never fully understood what was what, what to expect, and what to do,' said [FFS gardener]." (Field notes, 2/September/2011).

Several other gardeners also noted that they had received seeds previously, but never planted them because they weren't sure which ones would be best for their beds or exactly when and how to plant them. Participating in a research project provided an opportunity to learn about different cover crop choices and discuss which might be best suited to each of their plots. Some gardeners also felt that in-person support in the planting process was important. Contrasting the experience of participating in a research project as compared to other workshops at an FFS evaluation session, one gardener said,

> "Sometimes you go to a regular seminar, and you just sit down and you listen! … But here, I have to participate… It's not you go just an hour. It's a long, it's a process. I had… to help scatter the seeds, to see how it is done… scratch up the soil, 'OK, don't do it too deep' … It was not just, you tell me something, and I have to go home and look it up and look for it. Together! That was the next thing, yes. Together! You were with *us*. In the field… You *work* with us, you see? That's the difference with the research."

Having someone work with her seemed to provide the confidence to try something new – and participatory research provided a context for working together.

Looking back, I also see the importance of in-person support from what happened when I *didn't* do that. As the cover crops planted in our first year of research approached maturity, I discussed when and how to cut down the cover crops in a large-group meeting, but didn't hold workshops at each garden to teach gardeners how to do this. This was mostly due to time constraints: Since I held monitoring workshops just before sampling the cover crops, I was hesitant to ask gardeners to come out for another workshop so soon. Some gardeners were fine

with an explanation and a handout on cutting and mulching the cover crops, but others weren't sure what to do and found the task very difficult. After community educator partners and I followed up with gardeners about their experiences managing over-wintering cover crops in our first year of research, I wrote:

> "We [community educator partners and I] need to pay closer attention to ensuring that gardeners have the proper tools and know-how for cutting and mulching the cover crops… As we followed up with each gardener… we learned that a number of the gardeners had tried to pull up the cover crops (yikes, no wonder it was hard!) rather than cutting them at the base – despite my instructions at the spring meeting and (I thought) clear, one-page handout on managing the cover crops. 'But that is *not good enough*,' [community educator partner] repeated several times as we pondered gardeners' frustrations. 'We can't just tell them what to do; we have to go out to their gardens and *show* them this year.' I had to agree." (Field notes, 26/June/2012)

In our second season of research, I worked with one of the local organization sponsors to provide each garden with a pair of hedge shears and hold a workshop where we demonstrated, and gardeners practiced, cutting down the cover crops and leaving the shoots as mulch. With this additional support, the vast majority of gardeners found cutting down the cover crops to be a manageable task, and said they planned to use the same tools and technique in the future (Chapter 2). Thus, gardeners' positive responses when provided with hands-on guidance choosing and planting cover crops -- as well as their frustration when left with the task of cutting them down on their own in our first year -- demonstrate the importance of sustained, in-person support for enabling gardeners to implement agroecological practices. With planning and sufficient support from community educator partners, PAR can provide an opportunity for this hands-on, garden-based guidance.

<u>Strengthening the urban gardening community of practice</u>

Thinking beyond the immediate outcomes of improved stewardship practices to more dynamic community capacities and relationships, the FFS groups themselves exhibited aspects of communities of practice, and showed signs of contributing to and strengthening the larger urban gardening community of practice (Wenger, 2006). Here I draw on field notes and group evaluation sessions to outline how the FFS strengthened relationships between participating gardeners and contributed to the larger urban gardening community of practice during its existence. That said, I recognize that sustaining such relationships and contributions may be difficult without ongoing facilitation.

By engaging in collaborative research, participants in the FFS came together more frequently with gardeners in their own gardens, such as when we visited gardens to mark out cover crop plots or plant and monitor cover crops. Gardeners also visited other community gardens in their neighborhood for large-group activities, such as the workshops on cover crop choices, rotation planning, interpreting soil test results, and discussing initial research findings. Each of these gatherings, though related to the cover crop research, were also occasions for broader sharing of gardening knowledge (e.g., crops, practices, plants and seeds) as well as resources for strengthening gardens and communities more generally (e.g., greening organizations, small grant programs). For example, one garden had a strong connection to a local greening organization. When gardeners from two other gardens in the PAR group expressed interest in building compost bins, a gardener from the first garden pointed them to the organization as a source of plans, small grants, and even assistance from summer youth interns to build well-functioning compost bins. In this way, the FFS themselves functioned as communities of practice, where members "engage in joint activities and discussions, help each

other, and share information" (Wenger, 2006).

Beyond the small network of gardens participating in the FFS itself, many gardeners who participated in the FFS shared their new knowledge about cover cropping with others, including their children, youth participants in after-school programs, and other gardeners within and beyond their own gardens (as discussed above, 'Outcomes for Education: Leadership development'). After our second season of research, staff from one local organization sponsor noted that people from gardens *not* participating in the FFS requested cover crop seeds and row cover to protect the seed from birds, perhaps after hearing about the practice from FFS gardeners and/or seeing it in FFS gardens:

> **Staff member:** "I think because of those individual garden workshops and the consistency, what I saw is that people were cover-cropping at much higher rates than they have in the past. And especially people cover-cropping for the first time. And these are people who weren't just part of the Farmer Field School, they were people in gardens, or they were people who just knew you and knew what you were doing. So even if they weren't part of the research, they felt that practice and intention. Like, [non-FFS gardener] is cover-cropping for the first time this year. And she was super-resistant in getting involved because she's really busy, and couldn't commit herself to the full thing. But I think she was super-aware it was going on, and knew that other people were doing it, and wanted to buy in…".

> **Interviewer (MMG):** "Or talking with gardeners who were part of the Farmer Field School? And that were able to -- "

> **Staff member:** "Yeah! Yeah! Because she knew without me telling her, you're gonna wanna put row cover on [newly planted cover crop seed] so that the birds don't get it. She asked if she could have row cover, and I was like – that's never something I've really offered before, so that was interesting to see. And yeah, I went through so many boxes of cover crop seed, I gave it all out. A lot of people were doing it for the first time."

This story suggests the potential of PAR in community gardening contexts to contribute to ecological knowledge and practices in the broader urban gardening community of practice, both through oral communication (as participating gardeners recount their experiences) and imitation (as other gardeners observe practices being tested and improved) (Barthel et al., 2010).

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Table 2. Outcomes of participatory research on cover crops with Brooklyn gardeners, and design choices / practices that may have enabled them.

Outcomes of Brooklyn cover crop study ("What?")	Best practices ("How?")
• Enhanced scientific inquiry and gardening practice	• Collaborative research design and interpretation of results (incorporating local knowledge), through facilitated deliberation and informal conversations
• Knowledge of ecological processes in agriculture (e.g., nitrogen fixation, weed suppression) • Adaptive management skills (e.g., systematic observation, applying monitoring knowledge to improve practice)	• Outcomes monitoring using agroecosystem analysis (supported by simple checklists with visual guides and in-person assistance making and recording observations during monitoring workshops)
• Leadership development	• Provide opportunities & support for gardeners to share new knowledge with others (e.g., field days)
• Stewardship practices with environmental & agricultural benefits	• In-person support applying agroecological management practices (i.e., choosing, planting, monitoring, & managing cover crops)
• Enlarged and strengthened communities of practice	• Provide opportunities for gardeners to visit other gardens and engage in informal sharing of knowledge, practices, and resources

In summary, this case study of the Brooklyn FFS suggests potentially generative design choices and practices for achieving positive outcomes in PAR with community-based stewards of natural resources (Table 2). To enhance both research and practice, my gardener partners and I found it helpful to design and interpret our research in a collaborative way, such that the research reflected workable practices and our interpretation was informed by gardeners' knowledge of local conditions. Engaging gardeners in monitoring their plantings and evaluating the different cover crops built ecological knowledge and adaptive management skills. To develop participants' skills as leaders and educators, it was beneficial to facilitate opportunities for them to share their new knowledge with others, such as field days. For promoting improved stewardship practices, I found that it's essential to provide in-person support in selecting appropriate practices (in this case, cover crop combinations) for specific sites and implementing

those practices. Finally, providing opportunities for gardeners to come together and visit each other's sites may strengthen the urban gardening community of practice and contribute to sharing gardening knowledge, skills, and resources. All of these practices require a strong commitment on the part of scientist facilitators to visiting each garden on a regular basis and supporting gardeners in implementing stewardship practices, learning from the results, and sharing their learning with others.

In discussing identifying specific practices and experiences that may have facilitated positive outcomes in this PAR project with Brooklyn gardeners, I hope to contribute to understanding the methodological aspects of inquiry-based agricultural extension and the depth of commitment and individualized support it requires. I turn next to acknowledge its challenges, in order to stimulate conversation about how these barriers might be overcome to tap the potential of PAR in urban community gardening and natural resource management.

Challenges of PAR in community gardening contexts

While participatory research on ecologically-based management practices shows promise for facilitating a range of positive outcomes, there are challenges that make it difficult to put into practice and sustain in community gardening contexts. In the Brooklyn Farmer Field School, these challenges included:

- Addressing community-defined goals and priorities within the constraints of a discipline-specific dissertation project;

- Structuring participation to tap the educational potential of engagement in multiple stages of the research process, while limiting participants' time commitment to a feasible level;

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- Providing sufficient garden-by-garden research and education support with limited

  funding for community-based partners; and

- Designing accessible record-keeping forms and processes.

To address these challenges, facilitators of PAR must negotiate a number of tensions and foster synergies between different stakeholders' goals and priorities. In this section I describe my efforts (supported by the sponsoring local organizations and community educator partners) to seek solutions to, or at least mitigate, these problems throughout the Brooklyn FFS. However, I fully acknowledge that compromises, trade-offs, and difficulties remained with respect to all the issues mentioned above. For this reason, in the Discussion section I also suggest systemic changes that may support a fuller realization of PAR's potential benefits.

Centralizing community priorities in the research design & process

In this PAR project, there were significant tensions between *expectations for the design of academic research in the natural sciences* and *community control of the research topic and process*. Specifically, at least two common research design expectations conflicted with the PAR ideal of democratic decision-making processes that centralize community priorities (Anderson and Herr, 1999; Melrose, 2001; Mordock and Krasny, 2001; Greenwood and Levin, 2007; Cargo and Mercer, 2008); namely, a predefined disciplinary focus and assignment of cover crop treatments to plots based on planned statistical analyses. With regards to the disciplinary focus, two strategies may have created synergies with gardeners' needs and goals. First, as I publicized the FFS opportunity and conducted interest meetings, I was transparent about the broad research topic of cover crops and the types of management challenges it could address.

This likely resulted in self-selection of participants with a genuine interest in the topic. Second, as discussed above ('Results: Outcomes for Science: Relevant research'), I facilitated deliberative decision-making on specific management goals the research should address and practices to test, thus making the research process and findings useful to gardener participants.

With regards to the assignment of treatments, I negotiated allowing gardeners to choose which species they wanted to plant in their plots based on their management goals (although gardeners were often curious to try 'some of each,' resulting in a relatively even distribution of cover crop treatments across gardens). To account for variation in environmental conditions between plots and its effects on cover crop performance, I carefully documented soil properties and light availability in each plot for use in multivariate statistical analyses. However, embedding cover crop research plots within real community gardens (which had more similar soil and light environments within than across gardens), combined with gardener preferences for certain cover crop treatments in certain gardens, did result in some confounding of environmental variables. This limited my ability to draw precise conclusions about the influences of each (Chapter 2). Despite these limitations, the advantages of my approach were at least twofold. First, the scientific findings reflected environmental and management conditions in real urban community gardens, and thus provide a basis for informed cover crop selection in these settings. Second, gardeners had the opportunity to choose cover crops most likely to address their concerns with my guidance, based on knowledge of the scientific literature on cover crops generated from research station and on-farm studies.

While these efforts allowed for some degree of gardener influence over the research design, process, and outcomes for their gardens, the fact remains that gardeners had many interests and concerns that the predefined research topic did not address. To better integrate

these concerns into the FFS experience, I used two strategies. First, I used active listening (e.g., during workshops, research activities, and gardener interviews and group evaluation sessions conducted midway through the two-year process) to better understand and address gardeners' broader hopes and goals in the design of the FFS. Perhaps the most important example of this was when gardener interviews conducted between the first and second field seasons surfaced gardeners' desire to share new gardening knowledge and successful practices with others (see above, 'Results: Outcomes for Education: Leadership development'), leading me to encourage and support them in holding field days.

In our second year, I also scheduled several optional 'Gardener's Choice' workshops, thus creating an opportunity for genuinely open-ended decision-making by the PAR group regarding which topics they wished to explore further. Those who participated appreciated the variety and responsiveness to gardener concerns that these workshops provided. For example, a requested workshop on planting calendars and vegetable crop rotations was particularly popular, with many gardeners commenting on how useful it was informally and during group evaluation sessions. For example, when asked what activities worked well for developing gardening knowledge and skills during the 2012 group evaluation, one gardener noted:

> "Well the one [workshop on rotation planning] I attended in Bed-Stuy, that one was really interactive… You broke us in different groups and each of the groups was planning out, 'Well what do you plant in what part of the season.' And so each person was talking about, 'Well, I grow this, and this works good in these conditions…'. And there was like, 20-ish people there – so there was a lot of people with experiences in terms of what works here, and why it works. Also, some people planted things at different times, so that was interesting to talk about. So it was that open -- *experience* when there's a lot of people there who could talk about things…Having time at the meeting when people were like, 'Oh, this works for me, this is my issue'… whatever people were dealing with. Just that *space* is really helpful."

Thus, although 'Gardener's Choice' workshops could not replace open-ended decision-making

in the central topic of sustained inquiry in the FFS, they did provide an opportunity to integrate democratic processes and address community concerns in ways that gardeners found enjoyable and useful.

Creating a feasible time commitment for participants

Another tension in our PAR project involved trade-offs between the *educational benefits of deep engagement in research* and the *time required of participants*. Throughout this paper, I have referred to FFS participants as 'gardeners' because this was the common identity and interest that brought the group together. Of course, each 'gardener' also had many other roles and responsibilities to balance with their garden-related activities. Unlike typical FFS participants in smallholder farming settings – who generally farm full-time, and may have more flexible schedules -- two-thirds of Brooklyn FFS participants worked at other jobs. Many were also parenting children at home or caring for spouses or parents with chronic illnesses, and nearly all were deeply involved in other civic groups and volunteer activities. Reflecting on how she fit the FFS workshops into her life during an interview, a participant working to reconnect young people and seniors through her garden recalled:

> "It was hectic, but it was manageable, and I wouldn't have missed [FFS] workshops for the world because it has been *so helpful*. The seniors, *still* talkin' about it, sayin', 'Oh, the cover crop is so *green* in the box,' and she can't wait [to see its impact on the soil and next year's crops]…
>
> [Looking ahead to next year,] I said to my husband, last Friday, 'Listen here. We *got* to go to Staples.' He's like, 'What's your rush to go to Staples?' I said, 'I need to get my planner!' Because I have all of these trainings comin' up. For the Farmer's Market they have a convention some weekend comin' up…
>
> I'm going to tell you, Megan -- Some days I come home, and my husband tease me. He say, 'Not even President Obama have a schedule like you!' *[Laughter.]* But, you know what? ... I'm gonna tell you, it's the reward that I get out of workin' with the kids, and

workin' with the seniors. Because they are really rejuvenated. They are excited that they could come in the garden."

Given this reality, in facilitating the FFS I had to actively (and constantly) negotiate and 'feel out' a level of participation that met gardeners' goals for themselves and their communities, while respecting that they had limited time and energy to contribute to the project. In response to feedback from gardeners and community organization partners, in the second year of research I streamlined the series in some ways: for example, reducing the number of planning workshops from three to one, and monitoring each cover crop combination only once in the fall instead of twice. More generally, I came to appreciate the importance of striving for 'quality time,' not necessarily 'quantity time' when structuring gardener participation, as this excerpt from my field notes shows:

> "In a continuing effort to maximize gardeners' learning experience relative to the amount of time they devote to FFS workshops, I decided that this fall we would monitor each cover crop planting just once instead of twice… [A]s I've come to understand the realities of gardeners' lives – working two jobs, caring for kids, serving on community boards, etc. – I've developed greater appreciation for the time we have together. In this context, being a respectful facilitator means emphasizing the *quality* of the PAR experience over *quantity*. I've tried to ensure that every workshop experience makes a unique contribution in terms of improving stewardship practices in the gardens (e.g., the planting workshops), and/or generating new and useful knowledge (e.g., the monitoring workshops). I've come to see that if we can learn nearly as much from monitoring a cover crop two months after planting as we can monitoring at one *and* two months after planting, then it's important not to ask gardeners to come out twice." (Field notes, 15/October/2012)

Offering flexible scheduling of research activities and individualized support to accommodate different participants' schedules also enabled many gardeners to participate in the full research process, while respecting their other commitments. Such flexibility on the part of PAR facilitators may be particularly important when engaging people working in a wide array of jobs with distinct schedules, as in the Brooklyn FFS.

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That said, maintaining the integrity of the PAR project -- as a sustained process of planning, planting, monitoring, evaluating, and discussing cover crop plantings and practices together – did mean accepting that PAR is not for everyone at every stage of life. Not all gardeners with some interest in cover cropping practices were able or willing to commit to such intensive participation. This was a trade-off I recognized as I chose to retain the structure of both large-group workshops and hands-on research activities in gardens for the second year of the FFS. However, with an abundance of one-time workshops available from gardening and greening organizations throughout the city (Chapter 1; Gregory et al., 2016), I felt that I could fill a unique niche in community gardening education by offering a sustained, inquiry-based group learning process, even if this meant it would only be feasible for a particularly dedicated group of gardeners. Given that most gardeners in the Brooklyn FFS successfully balanced their participation with many other commitments, I believe the program structure was feasible even for busy working people, parents, and citizens, albeit with substantial effort by gardener participants and facilitator alike.

Providing individualized attention

I found that maintaining high-quality research and education required a tremendous amount of one-on-one, garden-by-garden support. This was a consistent theme in my field notes, given that multiple visits to each garden were required to accomplish each research activity (e.g., selecting cover crop treatments, planting during three seasonal windows, monitoring workshops for each group of cover crops, sampling cover crops, etc.). As I noted after mapping out cover crop research plots in the second year of the project:

> "Almost any book on participatory research will note the importance of time, patience, relationship-building, and other generalities… So what does it mean, in practice, to take

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the time and have the dialogue to map out a collaborative research design, one that is most likely to contribute to community goals while still being a deliberately planned experience we can learn from? For me, that meant that in order to decide what would be planted where, I made 24 visits to 13 gardens over almost two months to meet with gardeners, including multiple visits to many gardens to accommodate different gardeners' schedules." (Field notes, 28/August/2012)

As I continue on to note, the visits were valuable for building friendships, understanding gardeners' goals and cropping systems, and providing gardeners an opportunity for making informed decisions about cover crop selection for their beds. However, providing this degree of individualized attention for each research activity was time-consuming, and should have involved more than one person able to make the project a primary commitment in order to avoid facilitator burnout. Unfortunately, having very limited funding (and no long-term stability) for additional project staff was a major obstacle to providing the necessary support in a sustainable way.

Having anticipated a need for some assistance coordinating workshops, I did hire 'community educator partners' in each site, which partially addressed the need for additional facilitators (see above, 'Methods: Forming neighborhood-based PAR groups'). They provided invaluable support and insight into how to shape the PAR project and related extension materials to be accessible and relevant to the gardening community. During group evaluation sessions, other gardeners also emphasized that receiving personal reminders from community educator partners for workshops and research activities was helpful and motivating. However, with very limited compensation, all educator partners necessarily had other, primary employment and obligations. This meant they were (understandably) not able to make the PAR project a top priority, and were often unavailable when additional help was needed (for example, to assist individual gardeners at monitoring workshops and during cover crop sampling).

<u>Designing accessible record-keeping forms and processes</u>

In the Brooklyn FFS, much of my time (and community educator partners' time) was devoted to 'coaching' gardeners through data collection by making observations of cover crop plots, then recording and reflecting on their observations. Recording observations is important for generating new knowledge as well as building participants' adaptive management skills; however, I found that many gardeners were intimidated by tables and datasheets that require substantial writing. I addressed this issue by developing 'monitoring checklists' (Appendix B) with visual guides to facilitate gardeners' observations of each cover crop plot. However, even with these guides, I always provided one-on-one guidance as participants used the checklists to record their observations, often with support from community educator partners.

Discussion

This story of 'doing science' while striving to foster learning, leadership, and environmental stewardship with Brooklyn community gardeners resonates with scholarship on effective practices for public participation in scientific research, particularly with under-served communities such as the culturally diverse urban neighborhoods where I worked (Porticella et al., 2013a; b). Furthermore, it provides an example of how participatory agricultural research can be adapted to urban gardens, which have been historically under-represented in agricultural research and extension and where there is a need for horticultural recommendations tailored to local conditions (Guitart et al., 2012; Pfeiffer et al., 2014; Gregory et al., 2016). Despite the potential for positive outcomes of PAR, however, my experience also provides insight into the challenges that make such close-knit collaborations between agricultural scientists and urban gardeners relatively rare. In the first two sections that follow, I integrate my findings from this

case with the wider literature on agricultural extension, community education, and participatory research to discuss implications for two broad groups of stakeholders. First, I suggest promising practices for **scientist facilitators and community educators** seeking to achieve positive outcomes for science, education, and communities through PAR. In particular, I highlight how such practices can be applied to advance research and education with and for urban community gardeners. Second, I suggest how **institutions (e.g., colleges and universities, funders)** can create a more supportive environment for PAR through structural changes in policies and practices. I close by placing the Brooklyn FFS within the broader context of the urban neighborhoods where I worked and community-led efforts to address economic, social, and environmental challenges.

Integrating positive outcomes for science, education, and communities in PAR

Collaborative research processes informed by local priorities and knowledge; gardener participation in implementing agroecological practices and monitoring the outcomes; opportunities to share new knowledge with others; and intensive in-person support through the process – these practices all contributed to positive outcomes for science, education, and communities in the PAR project described in this paper. Evaluators of other community-research partnerships have identified similar design choices as keys to engaging under-represented groups and enabling a range of benefits in agriculture and natural resource management (Pence and Grieshop, 2001; Warner, 2007; Fernandez-Gimenez et al., 2008; Ballard and Belsky, 2010; Porticella et al., 2013a). Here I review project design choices and activities that may have enabled positive outcomes in the Brooklyn FFS and other participatory research efforts, and therefore have strong support to recommend them to community educators

and scientist facilitators of PAR.

<u>Design and interpret research projects collaboratively</u>

Scholars and supporters of PAR maintain that engaging practitioners in agricultural and

environmental research may strengthen the science by directing it towards relevant problems or

opportunities and incorporating multiple perspectives (Woodhill and Röling, 1998; Fischer,

2000; Mordock and Krasny, 2001; Wynne, 2003). In particular, lay citizens' local knowledge

can provide insight into options for practice and inform the design and interpretation of scientific

studies (Vasquez et al., 2006; Ballard and Belsky, 2010). In the Brooklyn FFS, gardeners'

knowledge of planting calendars and strategies for gardening in an urban environment (e.g.,

protecting crops from pigeons!) played key roles in choosing cover crops to test, understanding

initial results, and refining our planting practices. Similarly, salal[15] harvesters who collaborated

with forest ecologists to study the effects of harvest intensity on salal growth informed research

design with their knowledge of common harvest practices and forest conditions (Ballard and

Belsky, 2010).

Involving public participants in data analysis can also advance educational and

community goals, building their skills for using monitoring findings to adapt future practices and

their confidence to share what they learned with others (Fernandez-Gimenez et al., 2008; Bonney

et al., 2009). In the Brooklyn FFS, gardeners were involved mainly in the early stages of data

analysis. During monitoring workshops in individual gardens and periodic presentations of

monitoring data to the larger PAR group, I encouraged gardeners to compare and contrast cover

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[15] Salal is an evergreen shrub in Pacific Northwest forests harvested for use as greenery in the floral industry. Many migrant workers, mostly Latinos, depend on harvesting salal for their livelihoods.

crop treatments, consider implications for cover crop selection in their gardens, and suggest improvements in planting practices. I conducted most formal data analysis, mainly due to constraints of time and geography (analyzing soil and plant samples took substantial time after the conclusion of field work and occurred at Cornell University where there were suitable lab facilities). Nonetheless, between gardeners' involvement in monitoring workshops and discussing presentations of data from across gardens, they gained skills for testing and adapting cover cropping practices and shared their learning with others (as discussed above, 'Results: Outcomes for Education'). Experiences in community-based monitoring of both forest resources and water quality suggest that public participants may further develop such skills by taking part in data analysis workshops (Fernandez-Gimenez et al., 2008; Bonney et al., 2009; Ballard and Belsky, 2010). Indeed, in some of these cases participants only felt confident enough to share their findings with fellow community members, agencies, and policymakers after participating in data analysis.

Taken together, findings from the Brooklyn FFS and other community-research partnerships illustrate the importance of collaborative processes in agricultural and natural resource management research. Such processes may include structured group activities (e.g., facilitated deliberation about priority research goals and practices to test, data analysis workshops) and informal interactions as researchers and practitioners observe, puzzle over, and seek to understand the results of their management 'experiments,' and to do better the next time around.

Engage gardeners (public participants) in outcomes monitoring

The importance of cover crop monitoring for educational and environmental stewardship

outcomes in this PAR project also corresponds with previous experiences in participatory research (Pence and Grieshop, 2001; Warner, 2006, 2007; Fernandez-Gimenez et al., 2008; Silva and Krasny, 2014). For FFS gardeners, observing and reflecting on indicators of cover crop performance (e.g., soil cover, nodulation, weeds, etc.) enhanced their understanding of ecological processes and skills in choosing and managing cover crops for improved soil quality and weed suppression. This concurs with evaluations of the highly successful Biologically Integrated Orchard Systems (BIOS) partnerships, which engaged California growers in research on ecologically-based pest management (Hendricks, 1995; Pence and Grieshop, 2001; Warner, 2006, 2007). Growers in BIOS partnerships developed skills for agroecological pest, soil, and irrigation management techniques as they implemented BIOS practices in a block of their orchards and monitored the results. By analyzing the environmental and economic outcomes of different practices, they learned to refine their farming systems to be more productive, profitable, and environmentally sustainable (Warner, 2006). Similarly, a multiple case study of 18 collaborative monitoring efforts in community-based forestry found that monitoring increased participants' ecological knowledge and appreciation for the complexity of forest ecosystems in all cases. Many monitoring projects also resulted in adoption of more sustainable management practices by harvesters of non-timber forest products, timber companies, agencies, and private landowners (Fernandez-Gimenez et al., 2008). In urban contexts, community-based organizations working in urban agriculture and street tree care have also used outcomes monitoring to improve selection of crop varieties and street tree species (Silva and Krasny, 2014).

These diverse experiences affirm the educational value of outcomes monitoring for agricultural and natural resource management practice. My work with gardeners in Brooklyn

also demonstrates an effective method for facilitating such monitoring in urban gardening contexts, as called for by Krasny et al. (2014). Based on gardeners' management goals, in consultation with other agricultural scientists (L. Drinkwater and J. Grossman), I first developed a set of easy-to-observe indicators and a checklist with visual guides, to be filled out at defined times (in this case, two months after cover crop planting and at cover crop maturity) (Appendix B). I then held monitoring workshops where I explained the importance of each indicator and helped gardeners observe each plot and fill out monitoring checklists, with support from trained community educator partners. The checklists of cover crop performance indicators supported and structured gardeners' observations. They also provided a common framework for participants to compare and contrast outcomes across gardens, thus extending their understanding of how environmental factors should be considered when selecting cover crops. However, as in other projects (Porticella et al., 2013a), I found that in-person coaching was essential for honing participants' observation skills, bolstering their confidence, and helping them record and reflect on their observations to draw conclusions for their gardening practices. Other facilitators of PAR could use a similar strategy, combining simple checklists of indicators related to desired outcomes with in-person guidance collecting and reflecting on this information.

Convene and strengthen communities of practice

I found that fostering knowledge-sharing within and beyond the FFS supported participants' growth as educators, and may lead to community-level benefits for crop production and the environment as cover cropping practices are implemented and improved in the broader urban gardening community. As agroecological practices inspired by garden-based research spread

beyond gardeners in our PAR project, other agricultural extension initiatives utilizing on-farm research and demonstration have also engaged a broad community of growers. For example, in the previously mentioned BIOS partnerships, educational field days played a key role in developing grower participants' confidence and spreading ecologically-based practices. Like our field days, these events were held in participating orchards, featured grower-researchers sharing the results of new practices, and reached growers well beyond those enrolled in the research program with practical, locally relevant information. Ultimately, this contributed to widespread adoption of integrated pest management techniques and commodity-wide reductions in pesticide use that provided environmental and health benefits at the community level (Pence and Grieshop, 2001; Warner, 2007). Importantly, in both the Brooklyn FFS and BIOS partnerships, scientist facilitators encouraged gardeners and growers to share their learning, and provided support in planning and publicizing field days. To realize the full potential of participatory research to strengthen communities of practice, therefore, PAR projects should include intentional efforts to build participants' capacities and confidence to share their findings with fellow practitioners, policymakers, and other stakeholders.

Creating a supportive institutional environment for PAR

Despite the well-documented potential of the PAR practices outlined above to yield positive outcomes for science, education, and communities, this approach to research and education remains incredibly rare in agricultural and environmental fields.[16] Community-based

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[16] As a coarse indicator of the prevalence of participatory approaches to agricultural research, in a search of Thompson Reuters Web of Science, only 1.2% of the 'Agronomy,' 'Agriculture, Multidisciplinary,' and 'Horticulture' papers published from 1990-2015 that mentioned agriculture, horticulture, or gardening also contained the word 'participatory.'

organizations with interest in participatory research often struggle to secure partnerships with scientists that could advance their stewardship goals (Fernandez-Gimenez et al., 2008). Furthermore, in this case and in other community initiatives incorporating research, lack of long-term support for community researcher/educator partners likely constrained learning and action for healthier and more sustainable neighborhoods (Fernandez-Gimenez et al., 2008; Porter, 2013). Therefore, I turn now to a discussion of institutional changes that could inspire and sustain more participatory research partnerships.

Strengthen institutional support for long-term community-research partnerships

Through participatory research, scientists can facilitate knowledge-sharing and learning that leads to improved land management (Berkes, 2009). However, a supportive institutional context is essential for scientists to connect with community-based groups and invest in partnerships that facilitate social learning in agriculture and natural resource management (Buck, 2002). Since this PAR effort was situated within a dissertation project I undertook for a graduate program based in a natural science academic department, there was limited 'space' (and time) for gardeners to influence the central topic of our inquiry, though I sought to understand and address their goals as much as possible.

Truly centralizing community priorities in PAR would benefit from efforts at colleges and universities to create or strengthen institutional structures that invite community-defined questions or topics of interest, and match community organizations with faculty committed to long-term research partnerships. At land-grant universities, Cooperative Extension programs would be a natural 'home' for structures connecting citizens/residents and faculty, whether directly or through county- and regionally-based Extension educators. Indeed, the Cooperative

Extension System "was and is the official institutionalized means for land-grant faculty, staff, and students to reach beyond the campus and classroom," and a strong tradition of Extension work emphasizes democratic decision-making and community development, in and through collaborative work in agriculture, health, and other common concerns (Peters, 2010: 12, 39-46). Some programs and networking tools -- supported by universities, scientific societies, and nonprofits -- already exist to support community-driven research in specific topic areas (Soleri et al., 2016). These efforts could provide models for broader programs at colleges and universities committed to equitable community engagement that serves the public good.

In contexts of sustained community-scientist partnerships, community groups could refine their research questions and pursue multiple cycles of inquiry, action, and reflection with support from scientists and their graduate students (Krasny et al., 2014). Faculty and students, in turn, would enjoy opportunities to build meaningful relationships, conduct practical and locally relevant work, and develop diverse skill sets for community education and development. To ensure that researchers have the requisite perspectives and skills for reflexive, respectful community engagement, educational institutions could integrate research ethics and cultural humility training more systematically into their core curricula, faculty professional development, and workshops for community-based partners (Porticella et al., 2013a; Quigley, 2016).

Though this is beyond the scope of the present paper, I also note that structures to facilitate participatory research partnerships should be undergirded by broader cultural changes at colleges and universities as well as within Cooperative Extension. Realizing the full potential of equitable community-scientist partnerships will require that academic communities (particularly at research universities) reconsider their central purposes in ways that embrace and value a direct role for scientists not only in generating technical knowledge, but also in

cultivating citizens' and residents' knowledge and capacities to advance community well-being in the broadest sense (Peters, 2010: 58-60). This, of course, would lead to additional changes in policies and practices (e.g., standards for tenure) that have been thoughtfully and thoroughly explored by others (Ellison and Eatman, 2008; Sturm et al., 2011).

Provide support for community researcher/educator partners

Given the need to provide public participants with individualized support to facilitate robust educational and community outcomes from PAR (Bonney et al., 2009; Carney et al., 2012), I believe that funding programs supporting community researcher/educator partners are also needed to implement and sustain PAR projects in community gardening contexts (and likely in most settings). One of my biggest challenges was providing sufficient one-on-one support to gardeners in planting, monitoring, and managing the cover crops, learning from that experience, and sharing it with others. This concurs with FFS experiences in subsistence and commercial agriculture, which show that inquiry-based farmer group education is labor-intensive. Globally, most FFSs require public or donor financing to train and support skilled facilitators, including well-trained farmers (van den Berg and Jiggins, 2007; Braun and Duveskog, 2008). However, van den Berg and Jiggins (2007) argue that such costs may be justified by the unique potential of well-supported FFSs to improve farmers' skills for managing diverse agroecosystems, eventually leading to community-level outcomes for human health, environmental quality, and social organization. In the United States, ample funding for staff time to engage with individual participants was crucial to achieving positive educational and environmental outcomes in the aforementioned BIOS partnerships promoting integrated pest management (Warner, 2007), and in collaborative monitoring in community-based forestry (Fernandez-Gimenez et al., 2008).

Staff time for individualized support was also key to the success of a PAR project that provided 40 farmworker families with resources, education, and a peer network to promote home gardening and documented significant benefits for nutrition and health. In this case, health promoters from a community-based organization delivered educational information to families when they were unable to attend community meetings, and a team of five researchers also visited gardeners in their homes (Carney et al., 2012).

Given my experiences in the Brooklyn FFS and those of other participatory research facilitators, I believe that sustained support for community researcher/educator positions would yield tremendous benefits for PAR in urban community gardening and natural resource management. Based within local Cooperative Extension offices and/or community-based organizations, such community researcher/educator positions could facilitate co-development of culturally relevant PAR projects by grassroots groups and scientist partners, and provide support 'in the field' for accurate data collection, practical learning for participants, and implementation of best practices (Porticella et al., 2013a). Ongoing support from trained community researcher/educators would promote deep resident involvement in project design and likely facilitate more sustainable impacts than projects implemented with short-term grant funding -- and therefore with limited follow-up support for building on initial successes in improving gardening practices and community organizing (van den Berg and Jiggins, 2007; Braun and Duveskog, 2008). Almost all urban agriculture and environmental stewardship organizations require more staff to fully address the needs of their neighborhoods, including improved food access and nutrition, creation and stewardship of green spaces, and development of life skills, job skills, and leadership among youth and adults (Svendsen and Campbell, 2008; Daftary-Steel et al., 2015; Cohen and Reynolds, 2015). Community researcher/educator positions could partially

address this need for additional staff. In particular, such positions could play an important role in program evaluation by documenting physical, environmental, and social outcomes and promoting adaptation of future efforts to meet community goals. As such, I recommend that academic partners include substantial support for community researcher/educators in research grants, and that funders (e.g., foundations, local governments) recognize the potential value of permanent staff positions in Cooperative Extension and grassroots nonprofit organizations that are devoted to facilitating participatory research and education efforts.

PAR in a vibrant, but challenging urban context

Throughout this paper, I have focused on my research questions addressing the outcomes and challenges of PAR in urban community gardens. However, to do justice to the meaning and significance of my work with a dedicated group of Brooklyn gardeners, I feel the need to provide at least a small window on the urban context, at once vibrant and rough, in which we planted, watched, and learned together. Indeed, a strength of case studies is that they can consider and illuminate a study's broader context – ecological, social, economic, and cultural – and its relationship to the topics of interest (in this case, participation in collaborative research, learning, environmental stewardship, and community development) (Yin, 2008). This is particularly true for the present study, during which I lived in the community, gardened at two participating sites, and took part in the active urban gardening and greening network of Brooklyn and NYC. This included garden-related events (e.g., workdays, workshops and skill shares, meetings, harvest parties) as well as other activities important to gardeners and the organizations supporting them (e.g., birthday parties, funerals, community Farmer's Markets, cultural festivals, and volunteering for a youth development program led by one of the local organizations in this

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work). Such "prolonged engagement" not only enhanced the credibility of study findings

(Lincoln and Guba, 1985: 301; Maxwell, 2005: 110) but also allowed for building meaningful

relationships and experiencing the context of life in Brooklyn.

As I have hinted in our discussion of gardeners' other commitments, this context

encompassed inspiring examples of neighbors coming together to transform trash-strewn vacant

lots into beautiful and productive gardens, share fresh vegetables, mentor youth, teach cooking

classes, organize bustling Farmer's Markets, advocate for gardens and green spaces in City land-

use policies, enact restorative justice in schools, celebrate the artistic and cultural traditions of

Brooklyn's diverse population, and more. It also encompassed tremendous social, economic,

and environmental public health problems, as this excerpt from my field notes illustrates:

> "[W]hat's on gardeners' minds and hearts… extends beyond the garden to the well-being of their entire neighborhoods. This is something that I'm still not sure if or how to address through the Farmer Field Schools…. When I arrived [at a garden to mark out cover crop plots] and started chatting with [FFS gardener], she was terribly shaken by a shooting that had occurred on the block the previous day in the early morning… She expressed her fear for her immediate safety and that of her neighbors, as well as her growing sense that she had to be very careful about who she let in the garden, and about when garden activities took place – something that not all gardeners agree about:

> 'They didn't like it, but [gardener] was in here havin' a little birthday party for her daughter, a cook-out, and I asked them to please leave and lock up by 8 p.m. With all the shootings that's going on, I have to do it.'

> She shook her head sadly, looking at her plot. And I knew in my heart that while perhaps she was interested in improving the soil in the garden she had founded and led for 30 years, she would have been far more grateful for someone to come with a solution to the violence that was keeping our community in fear and distrust. Yet I was empty-handed. This is still something I have not come to terms with as I work on this little cover crop project in communities facing such difficult, societal problems that are obviously much larger than some oats and peas." (Field notes, 13/August/2012)

This was at least the third time that fatal shootings occurred in close proximity to FFS gardens or

participants' homes – not usually during hours when people tended to be out in the gardens, but

upsetting nonetheless. In the course of facilitating the FFS and conducting gardener interviews, I also learned of gardeners and communities struggling with discriminatory housing practices that displaced people living on low incomes, under-resourced public schools, insufficient employment opportunities for youth and adults, lack of 'safe havens' for children with enriching after-school activities, and other social problems that are likely common to marginalized neighborhoods in American cities where residents are striving to make a difference through urban agriculture (Daftary-Steel et al., 2015). This perspective gave me humility about the limitations of a PAR project focused largely on improving gardening practices, and deepened my admiration for my gardener friends who committed so much of themselves to this effort despite challenging circumstances. Whether and how PAR -- and the skills and connections among citizens formed through such efforts -- can contribute to addressing larger economic, social, and environmental challenges that urban communities face is a worthwhile question for further exploration, but would surely require more sustained support and time.

Conclusions

Urban agriculture and community gardens have taken root in cities across North America as residents strive to increase access to healthy food, green their neighborhoods, and strengthen the social fabric of their communities. To advance these goals through urban agriculture, however, there is a need for: 1) greater understanding of effective agroecological practices for urban environments, and 2) educational opportunities that foster ecological knowledge, adaptive management skills, and communities of practice in which gardeners can share agroecological methods and organize around other common concerns. This case study of cover crop research with urban gardeners suggests that PAR offers a promising approach to address some of these

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needs and illustrates facilitation practices that promoted scientific, educational, environmental, and social benefits in Brooklyn, NY. Generative design choices in my work with gardeners in Brooklyn included: collaborative research processes integrating scientific and local knowledge, engaging gardeners in monitoring agroecological outcomes of their practices, helping gardeners plan and lead field days, and intensive in-person support with gardening practices, data collection, and sharing our findings with fellow gardeners.

While such practices are not new – indeed, they have enabled a wide range of benefits in agricultural and natural resource management across diverse contexts -- they remain rare in both research and extension. To inspire and sustain participatory research partnerships, I recommend that colleges and universities establish or strengthen institutional structures to match community organizations with faculty committed to long-term partnerships, and integrate supporting skills (e.g., research ethics, cultural humility) into their core curricula. Furthermore, given the intensive in-person support required to realize the benefits of PAR, I recommend that both research and philanthropic funders support community researcher/educator positions based within local Cooperative Extension offices and/or community-based organizations.

In my short two years conducting PAR with Brooklyn gardeners, I had the privilege of co-creating practical new knowledge, nurturing skills for sustainable urban gardening and community leadership, and (literally!) sowing the seeds of improved stewardship practices. Other partnerships between communities and scientists, usually with limited staff and resources, have also shown the potential of PAR to integrate positive outcomes for science, education, and communities. What might this approach -- of respectful partnership and inquiry grounded in the needs and hopes of people and their places – yield if it were broadly encouraged and supported for the long haul of creating healthy and sustainable communities?

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Appendix A. Case study propositions

Propositions addressing the first research question (PAR design for positive scientific, educational, and community outcomes in urban community gardening contexts):

1. Fostering outcomes for science through PAR:

    a. Involving gardeners in designing agricultural research may make it more applicable to their practices.

    b. Involving gardeners in interpreting research results may strengthen research findings and improve future practices with their knowledge of local environmental conditions.

    c. Public (gardener) participation in research may be fostered through a combination of structured group activities (e.g., deliberation about priority research goals and practices to test, data analysis workshops), and frequent, informal interactions as scientists and gardeners observe and interpret the outcomes of stewardship practices together.

2. Fostering outcomes for education through PAR:

    a. Monitoring the outcomes of gardening practices using agroecosystem analysis (facilitated by simple checklists and in-person support at workshops) may contribute to positive educational outcomes, including:

       i.   Knowledge and understanding of ecological processes in sustainable agriculture

       ii. Adaptive management skills (e.g., regular observation, recording and reflecting on results, applying monitoring knowledge to improve practice)

    iii.   Excitement and enthusiasm in discovering, understanding, and nurturing

             ecological processes in gardens.

Despite this, some gardeners may feel that monitoring is too time-consuming.

b. Facilitating opportunities for gardeners to share new knowledge with others (e.g.,

    organizing and leading field days) may develop participants' identities as educators and

    leaders.

3. Fostering outcomes for communities through PAR (environmental and social benefits):

a. Sustained, in-person guidance selecting and applying agro-ecological practices (e.g.,

    cover cropping) builds gardeners' confidence and skills to implement such practices

    successfully, leading to potential agricultural and environmental benefits (e.g.,

    improved soil quality and vegetable production, reduced use of external inputs).

b. Providing opportunities for gardeners to meet regularly, visit other gardens, and share

    and reflect on their PAR experiences may strengthen communities of practice that

    contribute to sharing of knowledge, skills, opportunities, and resources that support

    local actions to create healthier environments and communities.

Propositions addressing the second research question (challenges of PAR in urban gardening education):

Some key challenges and potential solutions in garden-based PAR include the following:

1. Conflicts between *traditional research design* (e.g., a predefined disciplinary focus, research design based on planned statistical analyses) and *community control of the research topic and process* may be mitigated (though not eliminated) by:

   a. Transparency regarding the boundaries of the research project, such that participants have a genuine interest in the topic;

   b. Facilitating deliberative decision-making on specific priorities the research should address and practices to test;

   c. Listening to gardeners' broader hopes and goals, and finding creative ways to support those through the collaborative research experience and related group activities.

2. Trade-offs between *educational benefits of deep engagement in research* and *time required of participants* may be addressed by:

   a. Actively negotiating an appropriate level of participation that meets gardeners' goals while respecting that they have limited time to contribute to the project.

   b. Striving for 'quality time,' not necessarily 'quantity time,' when structuring public participation. Facilitators should assess the value of workshops and research activities in which gardeners are asked to participate in terms of how well a given activity makes a unique contribution to their learning and practice.

c. Offering flexibility in scheduling of activities and individual support to accommodate different participants' schedules.

3. To maintain high-quality research and education, PAR facilitators need to provide one-on-one guidance at each garden, at each step of the research process (e.g., selecting, implementing, observing, and evaluating stewardship practices at each site). This is difficult with limited support for project staff.

    a. Intensive, individualized guidance could be achieved through long-term financial and professional development support for community researcher/educator positions -- people from communities participating in research who are paid to assist with workshop scheduling, project development, facilitating implementation of best practices and monitoring workshops at individual gardens, and conducting program evaluation.

4. Data collection and reflection on observations can be made both systematic and broadly accessible through:

    a. Simple checklists of easy-to-observe indicators, linked to participants' goals for their management practices, with visual guides to facilitate observations.

    b. Monitoring workshops where scientist facilitators and/or trained community educators assist gardeners in making, recording, and reflecting on their observations.

Appendix B. Example checklist for monitoring over-wintering cover crops, adapted from versions used during the Brooklyn Farmer Field School.

Checklist for Monitoring Over-Wintering Cover Crops (for use in Spring)

Abbreviations: **C**= Crimson Clover   **V**= Hairy Vetch   **R**=Rye   **RC**= Rye/Clover   **RV**= Rye/Vetch

Cover Crop(s): _____   Garden: _____   Bed #: _____

Planting date: _____   Date of observations: _____

1. COVER CROP GROWTH

a) Visual % Cover (estimate using reference charts below): _____

| 10 % | 20 % | 40% | 60% | 80% | 95% |

b) Cover Crop Height: For mixtures, record **average** plant height.

Nonlegume (_____): _____ in   Legume (_____): _____ in

c) MIXTURES: Cover Crop Composition: % Grass: _____   % Legume: _____

d) Legume Flowering:

Date of first flowering (estimate): _____

crimson clover

% Flowering: ☐ 0%   ☐ 1-25%   ☐ 26-50%   ☐ 51-75%   ☐ 76-100%

hairy vetch

(The ideal time to cut down cover crops is when 75-90% of the plants are flowering.)

2. NITROGEN FIXATION: *Dig up two legume plants and examine the roots.*

	Plant 1	Plant 2
a) Count the nodules:	# Nodules: _____	# Nodules: _____
b) Inner Nodule Color:	☐ Mostly pink ☐ Some pink ☐ White or green	☐ Mostly pink ☐ Some pink ☐ White or green

Continued on reverse →

3. WEED SUPRESSION:

a) **Percent Weeds** (use percent cover charts to estimate): _____ %

b) **Most common weeds** -- List. Indicate weeds producing <u>seed</u> with a <u>star</u> (*)

_____   _____

_____   _____

_____   _____

c) **Compared with the control plot (no cover crop), the _cover crop plot_ has** (check one):

☐ More weeds   ☐ Less weeds   ☐ Same amount of weeds

d) **How satisfied are you with weed control by the cover crops?** (check one):

☐ ☹ Not satisfied – weeds are a major concern; cover crops did not help

☐ ☺ Somewhat satisfied – weeds are not bad; cover crops helped a little

☐ ☺ Very satisfied – weeds are not a problem; cover crops helped a lot

e) **Are there weeds producing seeds?** ☐ Yes   ☐ No

4. OTHER OBSERVATIONS (e.g., pests & beneficial insects; signs of disease, etc.):

_____

_____

_____

_____

_____

_____

Percent Cover Charts modified from Fig. 19 *in* British Columbia Ministry of Forests. 1997. Silviculture prescriptions field methods book. Online at: https://www.for.gov.bc.ca/hfd/pubs/docs/sil/sil411.htm.

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