Scaling Biochar: INVESTING IN SOILS, IMPROVING LIVELIHOODS, AND SEQUESTERING CARBON

Milestone 4: Field Officers Hired and Trained

Prepared by: Innovations for Poverty Action

PI: Andrew Crane-Droesch

Grant No.

AID-OAA-F-12-00016

August 15, 2013

Dear Peter Khaemba,

Please find in this submission CVs of the field officers hired under USAID Grant No. AID-OAA-F-12-00016, "Scaling Biochar: Investing in Soils, Improving Livelihoods, and Sequestering carbon."

The following field officers have been hired and trained:

Field Officer – Regular

- Kelvin Enderegwa Chagira
- Fredrick Kita Kidavasi
- Michael Odongo Esiaba
- Carolyne Acheng Musiko
- Philip Wabwile Mukhongo
- Sabasian Mangira Muhor
- Titian C. Korir
- Wanyonyo Nalua Zacchaeus

Field Officer – Casual Labor

- Rael Andisi Otwere
- Jasper Otieno Obwaya
- Wonyoni Moses Wanjala

I certify that these officers have been hired and trained in accordance with our grant agreement and in completion of Milestone 4.

Warm regards,

Lauren M. Oleykowski

Lauren Oleykowski
Manager, Global Program Operations

101 Whitney Ave., Second Floor, New Haven, CT 06510 U.S.A.
http://www.poverty-action.org

CURRICULUM VITAE

PERSONAL DETAILS

NAME	**:**	KELVIN ENDEREGWA CHAGIRA
DATE OF BIRTH	**:**	[redacted]
ID NO	**:**	[redacted]
MARITAL STATUS	**:**	SINGLE
ADDRESS	**:**	P.O. BOX 1537, MACHAKOS
NATIONALITY	**:**	KENYAN
TEL NO	**:**	[redacted]
EMAIL	**:**	[redacted]

PERSONAL PROFILE

Self motivated,initiative and Works towards the growth and upholding of the organizational vision through dedicated hardworking and commitment.

EDUCATIONAL BACKGROUND

2010 – 2012 : Kenya Institute of Social Sciences

Award: Diploma in Community Development and Social Work

April – May 2010 : Kenya Institute of Social Sciences

Award: Certificate in Computer Application Packages

2006 – 2009 : Kibabii Boys High School

Award: Kenya Certificate of Secondary Education

1997 – 2005 : Kanduyi Primary School

Award: Kenya Certificate of Primary Education

BACKGROUND INFORMATION

- NAMES: FREDRICK KITA KIDAVASI
- SEX: MALE
- MARITAL STATUS: MARRIED
- NATIONALITY: KENYAN
- RELIGION: CHRISTIANITY
- LANGUAGES: English, Kiswahili, luhya
- CONTACT: 0720110406
- [redacted]

1. CAREER OBJECTIVE

To utilize capacities in a dynamic environment so as to promote development within institutions, the community at large and myself

2. EDUCATION BACKGROUND

2008: Kenya institute of management (KIM)-Certifate in project management

1995-1998: Lugari secondary school-Kenya certificate of secondary Education

1983-1993: Manyonyi primary school-Kenya certificate of primary education

3. ACHIEVED SKILLS;

- **A valid driving license F and G.**

4. WORKING EXPERIENCE

2011-TO DATE: COMMUNITY FIELD ASSISTANT DISPENSERS FOR SAFE WATER, INNOVATIONS FOR POVERTY ACTION

- **Duties and responsibilities:**
  - Collecting data electronically and paper work
  - Administering of surveys using motorbike as means of transport
  - Office arrangement
  - Data entry
  - Making phone calls to partner organization
  - Site verification
  - Assisting in scheduling of field work on the ongoing one acre fund intervention
  - Attending to other duties as assigned by my supervisors.

CURRICULUM VITAE

PERSONAL DETAILS

NAME	:	MICHAEL ODONGO ESIABA
NATIONALITY	:	KENYA
ADDRESS	:	P.O. BOX 2500 – 50100 KAKAMEGA
TELEPHONE NO	:	[redacted]
		[redacted]
E-MAIL ADDRESS	:	[redacted]
DATE OF BIRTH	:	[redacted]
SEX	:	MALE
MARITAL STATUS	:	MARRIED
RELIGION	:	CHRISTIAN

ABILITIES

- Able to speak Luhya fluently
- Self driven and motivated.
- I am flexible.
- Hardworking.
- Working diligently and honest.

EDUCATION

COLLEGE EDUCATION

2007–2008

World sphere Training College - Kakamega

- Information Technology Certificate

2008

Imperial Driving School

- BCEFG Class

SECONDARY EDUCATION

1999 – 2002

Shieywe Secondary School

- K.C.S.E Certificate (D Plain).

CURRICULM VITAE

PERSONAL DETAILS

NAME : CAROLYNE ACHENG MUSIKO
ID NUMUBER : [redacted]
GENDER : FEMALE
MARITAL STATUS : SINGLE
RELIGION : CHRISTIANITY
LANGUAGE SPOKEN ENGLISH, KISWAHILI AND LUHYA
POSTAL ADDRESS : P.O. BOX 268-50409
NAMBALE
TEL NUMBER : [redacted]
EMAIL ADDRESS : [redacted]

Career Objective:- To develop skills and work hard in quest for excellence in my profession through engagement in a competitive and challenging organizations that demands strong social, organizational, interpersonal and management skills in the areas of community development.

Personal profile:-Self-motivated, ability to work under minimum supervision, goal oriented, dedicated, team builder, socially efficient, good problem solving and decision making skills, determined and reliable with a drive to be trained and learn quickly.

WORKING EXPIRIENCE

2011(MAY-PRESENT): INNOVATIONS FOR POVERTY ACTION (KENYA)

Field Officer

Responsibilities

- Formulation of questionnaire and survey administration.
- Participated in data collection, management and entry.
- Carried a research on farming methods and barriers to fertilizer use in Kenya.
- Training communities on income savings and administration of financial surveys.
- Taking census of respondents/study subjects.
- Providing health education on solid waste management.
- Acted as a team leader.

2011 (MARCH-MAY): INTERIM INDEPENDENT ELECTORAL COMMISSION

BIO DATA CURRICULUM VIRTAE

AME: PHILIP WABWILE MUKHONGO.
DRESS: BOX, 331 BUNGOMA.
ATIONALITY: KENYAN.
OME COUNTY: BUNGOMA.
) NUMBER: [redacted]
ATE OF BIRTH:
EX: MALE.
IARITAL STATUS: MARRIED WITH ONE CHILD.
ELIGION: CHRISTIAN.
ANGUAGE: ENGLISH, KISWAHILI, LUYHA (BUKUSU) FLUENTLY SPOKEN AND WRITTEN
ONTACT: [redacted]
MAIL

PROFILE

AM COMPETENT PERSON WITH POSTIVE OUTLOOK AIMING AT PARFECTION

EDUCATION BACKGROUND

991-1994 ST JOSEPH NAIROBI PRIMARY SCHOOL.

995-1999 SAMOYA PRIMARY SCHOOL(363 MRKS)

000-2003 MAHANGA SECONDARY SCHOOL(C-)

011 -2006 GATE TECH COMPUTER COLLEGE(DISTINCTION)

WORKING EXPERIENCE

004: WORKED WITH PSI NGO IN WESTERN NYANZA AGAINST MALARIA INFECTION AND AS A SALES EXECUTIVE PERSONNEL IN CELTEL COMPANY LIMITED

005: WORKED AS A VOLUNTEER WITH WORLD VISION THROUGH RADIO PROGRAM (WEST FA AS PEER EDUCATOR

009: WORKED WITH KENYA RED CROSS, APHIA II WESTERN, UZANII THEATRE AS A VOLUNTEE

010: WORKED AS A SALES MAN IN OILIBYA PETROLEUM COMPANY

2301

CURRICULUM VITAE

FULL NAME: SEBASTIAN MANGIRA MUHOR

DATE OF BIRTH: [redacted]

GENDER: MALE

CITIZENSHIP: KENYAN

EDUCATION:

PRIMARY: 1992 – 1999 –KIBOS PRIMARY SCHOOL-KISUMU.- (PASS)

SECONDARY: 2000-2003 - HONO SECONDARY SCHOOL-SIAYA.- (D-)

ID NO. : [redacted]

DRIVING LICENCE NO: [redacted]

PROFESSION: DRIVER

WORK EXPERIENCE: -SONY SUGAR COMPANY (DRIVER)

-ELECTORAL COMMISSION OF KENYA (CLERK)

-ANA KWA ANA SELF HELP GROUP (COMMUNITY ADVISOR)

MARRITAL STATUS: SINGLE

TELEPHON NO: [redacted]

REFEREES:

1. TERESA ADHIMBO ONYURO
   P.O.BOX 845
   SIAYA
   CELL NO 0722840976

2. JAMES OGOLA
   P.O.BOX 144-50400
   BUSIA
   CELL NO 0725938989

3 STANLEY EVODO KIVUYA
P.O.BOX 600-50400
BUSIA
CELL NO. 0711705418

CURRICULUM VITAE

NAME: Titian C.Korir.

DATE OF BIRTH: [redacted]

SEX: Female.

NATIONALITY: Kenyan.

LANGUAGES: English, Kiswahili, Luhya, Kalenjin

ID NUMBER: [redacted]

MARITAL STATUS: Married

RELIGION: Christian.

ADDRESS: Box 1030 Bungoma.

CELL PHONE: [redacted]

EMAIL:

PERSONAL OBJECTIVES:-

- To work with a growing organization that can offer opportunity where my knowledge and skills can be used to achieve the organizational set goals.

PERSONAL QUALITIES:-

- Sociable
- Team player
- Self driven/self motivated.

EDUCATION BACKGROUND:-

2004 May to 2007 May Lake Institute of Tropical Medicine
Diploma in Community Health and Development
Key areas of study:

- Maternal Child health and family planning

CURRICULUM VITAE

PERSONAL DETAILS

NAME: WANYONYI NALUA ZACCHAEUS
DATE OF BIRTH: [redacted]
SEX: MALE
NATIONALITY KENYAN
ADDRESS: BOX .153 KIMILILI
ID NO: [redacted]
MARITAL STATUS: MARRIED
RELIGION: CHRISTIAN
LANGUAGE: KISWAHILI, ENGLISH, & LUHYA
TELEPHONE: [redacted]
EMAIL:

EDUCATION

2006-2008: SHANZU TEACHERS TRAINING COLLEGE IN MOMBASA.I DID DIPLOMA IN BUSINESS ADMINISTRATION WHOSE EXAMINATION BODY WAS KENYA NATIONAL EXAMINATION COUNCIL [KNEC] DATED 12TH NOVEMBER TO 21TH NOVEMBER 2008.

1998-2002: FRIENDS SCHOOL KAMUSINGA HAVING ATTAINED KENYA CERTIFICATE OF SECONDARY EDUCATION [K.C.S.E]

1989-1997: ST. PETERS' MUMIAS BOYS BOARDING PRIMARY SCHOOL HAVING ATTAINED KENYA CERTIFICATE OF PRIMARY EDUCATION [K.C.P.E]

WORKING EXPERIENCE

Industrial attachment in Bungoma Municipal Council in May –August 2007 in the office of Human Upon completion of my college I stated working with a research organization as from 01-09-2009 by the name Innovations for Poverty Action based in Busia County [I.P.A]. It innovates and evaluates cutting-edge approaches to solving development problems. I.P.A promotes the adoption of those proven impact through dissemination of results to policy makers, practitioners and donors as well as the actual design and implementation of new programs at a national level. I have worked with fertilizer in Western region with an aim to examine the barriers to fertilizer usage and to find innovative approaches to overcome them. I was employed as a field assistant in fertilizer project. My performance in fertilizer project was excellent which enabled IPA management to promote me to a higher level from field officer as of 01/06/2010 to date in a new project by the name change microfinance management program (C.H.A.M.P) with an aim to find out the effect to change in business due to lack of change by businesses in western region of Kenya. I later worked with Biochar project with an aim to find out the effect of new technology in farming in western region of Kenya

CURRICULUM VITAE

PERSONAL INFORMATION

Names : Rael Andisi Otwere

Date of Birth : [redacted]

Gender : Female

Marital status : Married

Languages : English, Kiswahili, Luhya

Nationality : Kenyan

Postal Address: P.O. Box 8, Kilingili

Cell Phone : [redacted]

E-Mail Address : [redacted]

CAREER OBJECTIVES

To apply skills, attitudes and competent knowledge to serve diligently in a competitive, challenging and dynamic environment while contributing to the realization of the objectives of the organization and positively impacting colleagues and the society at large.

PERSONAL PROFILE

- Good communication skills and leadership capabilities
- Strong analytical and interpretational skill in problem solving
- Good committed responsible and able to work with no or little supervision

ACADEMIC QUALIFICATIONS

PERIOD	INSTITUTION	QUALIFICATION
1996 -1998	Kenya water institute (KEWI)	Diploma in Water Technology
1991 – 1994	Kilingili Secondary School	Attained a Mean Grade of C Plain
1983 - 1990	Wamage Primary School	KCPE Certificate

OTHER COURSES

- Engineering course
- Communication skills course
- Team building course

CURRICULUM VITAE

CONTACTS

P.O Box 1250-50200, Bungoma

Mobile: [redacted]

[redacted]

PERSONAL DATA

NAME: Obwaya, Jasper Otieno

I.D. NO: [redacted]

GENDER: Male

DATE OF BIRTH: [redacted]

COUNTY: Migori

NATIONALITY: Kenyan

RELIGION: Christian

PERSONAL QUALITIES

A fast learner, deadline oriented, disciplined, honest, hardworking and determined.

ACADEMIC QUALIFICATION

Aug 2008- Dec 2012: Egerton University,second upper class honours in Bachelor of Science, chemistry option.

Feb 2003- Nov. 2006: Teremi High School, Kenya certificate of secondary education. Obtained a mean grade of A- (minus) of 76 points.

2002: Kanduyi D.E.B Primary school. Kenya Certificate of Primary Education.; 328 out of 500 marks.

1996 – 2001: Wi – kodongo primary school for class two to class seven.

1994 – 1995: Kanduyi D.E.B primary school for nursery level and class one.

WORK EXPERIENCE

Sept 2012-Apr 2013: Volunteered as an assistant teacher at Sichei friends secondary school.

May 2013 to June 2013: Working as a field officer with Innovations for Poverty Action- Kenya in the Biochar Project.

July 2013 to date: Working as Data Entry Consultant in the WASH Benefits project with Innovations for Poverty Action.

CERTIFICATES AND AWARDS

2013: Certificate of commendation for having organized District Kenya Science and Engineering Fair competitions as a patron.

2011: Certificate of acknowledgement, recognition and honor of performance in third year chemistry in the department of chemistry.

2011: Certificate of participation in the Kenya University Students competition in the 'Chemistry in everyday life' competition.

HOBBIES and INTERESTS

Computing, Traveling and Researching.

GENERAL SKILLS

Computer literate; familiar with Ms Word, Excel, Power Point, Internet and E-mailing.

Analytical skills, numerical skills and Research skills.

Good interpersonal skills

Data collection skills

Teaching skills

Data entry skills

|Resume.

WANYONYI MOSES WANJALA.

P.o Box 49-00221, Matathia Central

Kenya.

[redacted]

OBJECTIVES: TO OBTAIN A FULL-TIME JOB AS A.....

HIGHLIGHTS OF QUALIFICATIONS

- Fluent in *English*, *Kiswahili* and *Luhya*.
- Ability to work within a fast-paced environment under tight deadlines.
- Proficient in Microsoft applications.
- Capable of working independently as well as within a productive team.
- Enjoys taking on new challenges.

VOLUNTEER WORK EXPERIENCE

Duration	Position	Institution
Jan.2012-Mar.2012	Volunteer- Environmentalist	Lari Health Centre Kenya

Sept.2011-Mar.2012	Volunteer-Environmentalist	Kenvo-CWY, Canada.
Sept.2011-Nov.2011	Volunteer-Researcher	University of Ottawa, Canada.
Sept.2011-Nov.2011	Volunteer-Peer Educator.	Youth service Bureau, Canada.
Jun.2011-Sept.2011	Volunteer-Environmentalist	kenvo, Kimende, Kenya.

WORK EXPERIENCE

Duration	Position	Institution
Jan.2011-Mar.2011	Monitoring&Evaluation	Action Community Environment
Jan 2010-April 2010	English Literature Teacher	Nangwe Girls High school.
Jan 2010-Sept.2011	English Literature Teacher.	Namilama High school.
Jan 2008-Sept.2010	English Literature Teacher.	Misanga High school.
Jan 08-Sept.08	Volunteer. (Youth facilitator).	Ministry of Youth Affairs

EDUCATION BACKGROUND

REFEREES

1. MR. CHRISPINUS MUSUNGU
   PHONE NO. 0720812436
   Email cmusungu@poverty-action .org
2. MR. CHARLES JUMA MISIATI
   PHONE 0721721073
   Email cmisiati@poverty- action.org
   Cv valid as of 29-06-2013

- Primary Health Care
- Basic Guidance and Counseling
- Community Based Education
- Project Planning & Management
- Advocacy Skills
- Research Methodology
- STI/HIV/AIDS Management
- Environmental Conservation
- Village Vector & Housing Control.
- Mental Health
- Leadership Skill
- Community Mobilization & Participation
- Community Nutrition and Food Security
- Safe Water Supply & Sanitation
- Nursing skills

2005 June-November (Lake Institute of Tropical Medicine)
6 months training on psychological counseling
Key areas of study:

- Self awareness
- Theories of counseling
- Human growth and development
- Practice counseling
- Counseling applications

1999 -2002:-Kaptagat Girls High School and sat for Kenya Certificate of Secondary Education(K.C.S.E)in the following subjects:Maths,English,Kiswahili,Chemistry,History,C.R.E,Biology and Commerce.

Mean Grade C (PLAIN).

1990 -1998:-Iten Primary School and sat for Kenya Certificate of Primary Education(K.C.P.E)in the following subjects:Maths,English,Kiswahili,C.R.E,G.H.C,Homescience,(Art,Craft&Music),Science and Agriculture.

<u>OTHER QUALIFICATIONS</u>:-

2009 Computer Proficiency Certificate
Applications: Ms Office, Ms Excel, Ms Access, Outlook, Arc View 312, Spss

2007 Kenya Red Cross Society
Three months training in Community Based First Aid

WORKING EXPERIENCES:-

2011 May to Date
Innovations for Poverty Actions (IPA)
Position: Field Assistant
Responsibilities:

- Surveying and monitoring spring and well locations
- Compiling spring user lists
- Administering household questionnaires
- Monitoring user committees
- Organizing data collected from the field
- Data entry
- Occasionally appointed as team leader during field surveys

2008 April to 2011 April
Action in the Community Environment in Africa (ACE)
Position: Intern
Responsibilities:

- Community mobilization
- Coordination of community social enterprises
- Training of community volunteers
- Coordinate field activities in line with donor demands
- Collect and collate relevant project data
- Compile periodic reports
- Data entry of project activities in designed M&E system
- Liaise with government counterparts and other partners in the project sites
- Maintain links with other service providers in the operational areas

OTHER SPECIAL SKILLS:-

- Good leader
- Excellent in organization of activities

HOBBIES AND INTRESTS:-

- Badminton
- Scrabble
- Site seeing
- Research and reading
- Offering social welfare services

REFERREES:-

1. Celine Gratadour
   Programme Manager P.M.I Bungoma
   Cell phone: 0713936102
   Email: cgratadour@poverty-action.org

2. Augustine Wasonga
   Executive Director ACE- Africa
   Cell phone: 0722831835
   Email: augustine@ace-africa.org

3. Kennedy Opondo
   Director of programs KMET
   Cell phone: 0723636425
   Email:opondoko79@yahoo.com

* SINGING
* TRAVELLING

REFEREES

1. STEVE OIRO
   PSI CONSULTANT
   BOX 1272, KISUMU
   0724943446

2. JUDITH OKUNGU
   WORLD VISION CORDINATOR
   0726610862

3. DR. MOHAMMEDSAID
   KENYA RED CROSS/UZANII
   BRANCH CHAIRMAN
   0720283053

4. TERRY MBAKATA
   APHIA II WESTERN
   0729346660

Registration Clerk

Responsibilities

- Receive voter registration materials from the Deputy Registration Officer.
- Check the eligibility of the applicants before registering them.
- Ensure all the registration materials are accurately filled and shaded.
- Submit daily and weekly returns to the head clerk.
- Keep in safe custody all the registration materials.

2009(APRIL)-2010 MARCH: OVERCOMING FAITH SCHOOL-NAMBALE

Teacher

Responsibilities

- Empowering pupils with knowledge and skills.
- Guiding and counseling the pupils.
- Acts as a role model.

2009(AUG): KENYA NATIONAL BUREAU OF STATISTICS

Enumerator

Responsibilities

- Training and identify the enumeration area.
- Collecting all the materials required for the exercise.
- Asking questions, filling the questionnaires and error checking them.
- Being polite, patient, presentable and tactful.

2005(AUG-SEPT): AFRICAN COTTON INDUSTRIES-MOMBASA

Packager

Responsibilities

- Sealing and packaging of goods.

EDUCATIONAL BACKGROUND

COLLEGE EDUCATION

2006-2008 TAMBACH TEACHERS'COLLEGE

COURSE PI CERTIFICATE successfully completed PI course and attained CREDIT of 18 points.

2003-2004 KENYA COLLEGE OF COMMERCE AND HOSPITALITY

COURSE CERTIFICATE IN BUSINESS EDUCATION ONE

CERTIFICATE IN COMPUTER APPLICATIONS

- Introduction to computers
- Microsoft Word
- Microsoft excel
- Microsoft Access

SECONDARY EDUCATION

1998-2001 OUR LADY OF MERCY GIRLS SECONDARY SCHOOL-BUSIA, ATTAINED A MEAN GRADE OF C+

PRIMARY EDUCATION

1990-1997 ST AGNES-MANYOLE PRIMARY SHOOL

AMBITIONS

Pursuing academic excellence Business Related Studies

Pursuing a degree in teaching.

HOBBIES

- Traveling
- Reading Novels and magazines
- Making Friends

REFEREES

1. THE PRINCIPAL
   TAMBACH T.T.C
   P.O BOX PRIVATE BAG
   TAMBACH.
2. THE PRINCIPAL
   KENYA COLLEGE OF COMMERCE AND HOSPITALITY
   P.O BOX 17041
   NAIROBI.

3. PROJECT COORDINATOR MIWA PROJECT –IPA MUMIAS
   P.O BOX 1906
   BUNGOMA .

PRIMARY EDUCATION

1990 – 1998

Matende Primary School

- K.C.P.E

WORKING EXPERIENCE

August 2011- July 2012

Innovations for Poverty Action,

I worked as a Community field assistant and I was involved in:

- Water point nomination and verifications.
- Data collection using hard copies and smart phone.
- G.P.S readings.
- Water quality test from the field.
- House hold list collection.

Jan 2009- Dec 2009

PROMOTION OF PRIVATE SECTOR DEVELOPMENT (PSDA)

Major activities involved in were:

- Mobilization of community members.
- Sensitization of community members for jiko kisasa project.
- Education meeting about the jiko.
- Installation of the jiko

Jan 2006- August 2009

Taxi driver

OBJECTIVE

- To be a competent Public Officer.

HOBBIES

- Driving, Travelling, Listening to music and Exercising.

REFEREES

1. JOHN WEKESA,
   TELECOM KENYA,
   P.O. BOX 2500-50100.
   020-2037060.
   KAKAMEGA.

2. EDITH AJEMA,
   MUKUMU GIRLS SECONDARY SCHOOL,
   P.O. BOX 2500-50100.
   0720-966918.
   KAKAMEGA.

3. MOSES BARAZA,
   AREA COORDINATOR,
   DISPENSER FOR SAFEWATER,
   P.O. BOX 373 – 50400.
   BUSIA, KENYA.
   TEL: 0705158172
   mbaraza@poverty-action.org

2006—2008: Changoi self help group, secretary

Responsibility, 1.writing and distributing meeting notice on time to committee members. 2. Liasing with chair person on scheduling meeting dates.3. Taking minutes during meetings. 4. chairing the meeting in the absence of the chair person. 5. Working together with other team member on scheduling time frame for each project.

2001-2008 George Williamson Tea Estate: Field Supervisor

- **Duties:**
  - Ensuring worker reach at work on time
  - Workers plucked quality tea
  - Taking register of workers
  - Ensuring pluckers maintained TABLE LEVAL of the plant
  - Solving problem between workers
  - Forwading workers issue to management and giving them feedback

MARCH - August2010: Interim Independent Electoral Commission (IIEC) Lugari constituency

- Voter registering clerk; duties, 1. Making sure I have all the necessary material on time. 2 Checking register regularly to avoid double registration. 3.Registering voters. 4. I was the in charge of the station.
- Voting and counting clerk during referendum; Responsibility, 1. Guiding voters on the procedure of voting. 2. Verification between valid vote and the disputed one. 3. ensuring voting law are adhered to . 4. Verifying voters card register to see weather they tie. 5. Accompanying ballot boxes to the compiling hole. 6. Ensuring one person one vote by dipping the small finger of a person who has voted in permanent ink.

2011 JAN-AUG: **Pioneer Teacher at Manyonyi secondary school**:

PLAN

1. Borrowing leaning materials from well wishers and neighbouring school.
2. Seaked permission from the local administration and education ministry.
3. Admission of student
4. Working longer hour with little or no cash
5. Encouraging fellow staff to work hard so that our set goals succeed
6. Last but not least am proud today because the school is now gaining momentum

REFEREES

MR.**MOSES** BARAZA

Program coordinator

Dispenser for safe water

Innovations for poverty action

Contact: 0724702806

Ms. **NELLY** WAMBOI

Field associate

Dispenser for safe water

Innovations for poverty action

Contact: 0726861233

DIVISION MANAGER

WILLIAMSON Tea Company

P.O.BOX 124,

KERICHO.

WORK EXPERIENCE

September 2012 to present : Innovation for poverty Action

Position : Team Leader/field officer

January 2011-June 2012 : Relief Foundation

Position : Mobilizer/Facilitator

April 2011-May 2011 Exodus Children Home

Position : Assistant procurement officer

August 2010 –August 2011 : Life Skills/HIV/AIDS awareness Training Program among out-of-school youths.(-**Personal Initiative**)

AWARDS

Most innovative student – Kenya Institute of Social Sciences (2011)

National Award in Badminton (2007-Secondary school competition)

RESPONSIBILITIES

April 2013- present : **Innovation for Poverty Action**

Team Leader

Feb – Nov 2011 : **Relief Foundation**

Workshops and outreaches mobilization(HIV/AIDS).

T/Leader of Workshops and outreach mobilization teams.

Aug 2010 – Aug 2011 : **Kenya Institute of Social Sciences**

Student Body - Welfare Leader (Elective Post)

Hobbies

-Traveling

REFEREES:

Mburu Evans

Kenya Institute of Social Sciences

Director of Studies

Cell: 0717-421 272

Email add: kissje@gmail.com

Ben Wekesa

Innovation for Poverty Action(NGO)

Assistant Project Manager

cell phone: 0725161171

Email add: bwekesa@poverty-action.org

David Mwangi

Digital Opportunity Trust

Field officer -eastern province.

Cell phone: 0725 132 851

Email add: dmwangi@dotrust.org

Scaling Biochar: INVESTING IN SOILS, IMPROVING LIVELIHOODS, AND SEQUESTERING CARBON

Report on Baseline Survey

Prepared by: Innovations for Poverty Action

PI: Andrew Crane-Droesch

Grant No.

AID-OAA-F-12-00016

Scaling Biochar: Report on Baseline Survey

Andrew Crane-Droesch

31 July 2013

1 Overview

Project activities began in earnest in May, first by selecting and confirming specific geographic areas for project implementation, and then by rolling out our baseline survey in those areas. The baseline survey began in late May and was largely finished by the middle of June. Detailed agricultural, demographic and economic data were collected from 1077 households, and a summary of those data is presented in this report. Following completion of the baseline survey, households were randomly selected to receive biochar demonstration plots. We are currently in the process of demarcating and establishing those demonstration plots; completion is expected by early September after the last farmers harvest maize planted for the long rains, and prepare plots for the short rains.

We expect to begin offering biochar production services for sale around late November or early December. This corresponds to the period when the demonstration plots will begin to provide evidence about biochar's benefits, and when farmer liquidity will increase after the short rain harvest. Inducements to uptake will be randomized; test plots, subsidies, and "free trial" offers. This randomization will allow us to estimate more and less-effective means of stimulating technology dissemination, while also providing us with statistical instruments for identifying the causal effects of biochar adoption on crop yields, complimentary input expenditure, and whole-farm profitability.

The following section of this report outlines our activities over the past reporting period. Results of the baseline survey are then presented, followed by basic checks confirming that our randomization yielded treatment and control groups that were approximately balanced in terms of observable characteristics. The report concludes with a discussion of next steps, including one minor change to our implementation strategy.

2 Activities

2.1 Area selection

Geographic areas for project implementation were selected from a pool of 75 random coordinate draws from a circle centered on Bungoma. From this pool of potential project locations, we chose points closest to Bungoma where neither Re:char nor ACON had conducted biochar outreach work. Each selected point determined the center of a 4 km^2 "zone," which constituted our sampling frame. Zone sizes and numbers were based on our target sample size of 1000, and Kenyan government statistics giving average population densities for the administrative regions in which we are operating.

2.2 Stakeholder Consultation

After identifying target villages, we initiated contact with local stakeholders representing those villages. We began with district commissioners, who in turn put us into contact with village chiefs. We introduced the project to each of these stakeholders, discussed implementation schedules, displayed survey instruments, and answered questions. DC's/chiefs often provided valuable local information and introductions, assisting project rollout considerably. In particular, chiefs mobilized local elders to go house-to-house on our behalf, informing residents that our surveyors would be visiting. This was particularly important given recent nighttime attacks in the area, which had led the population to be suspicious of un-introduced outsiders. It also facilitated the collection of semi-sensitive information such as education level, polygamous marriages, etc.

2.3 Data collection

Our survey was collected electronically, using Open Data Kit software on Android tablets carried by a team of Kenyan field officers. Use of computer-assisted personal interview techniques allowed us to collect data more quickly, less expensively, and analyze data in real time. Doing so on paper would have been costlier and led to several-month lags for data entry, while real-time data collection allowed us to rapidly course-correct where necessary, and ensured high-quality collection by enabling close oversight of field teams.

Geographic coordinate data for each household was collected via handheld GPS units assigned to each surveyor. Identification of respondents was facilitated within our survey areas using satellite images, from which roofs of houses were clearly distinguishable. This combination of remote sensing and ground-truthing allowed us to ensure that nearly all households within our sampling frame were efficiently identified and visited. Selected zones, and the location of surveyed households within them, are given in figure 1.

2.4 Logistics

Eleven field officers were hired and trained in May 2013. While many had performed similar surveys before, our training built new capacity to do so using tablets, and to navigate by GPS. With training and experience, time taken to complete a survey dropped substantially below the equivalent time for a paper survey. Each day, surveyors were given a list of coordinates (identified from satellite images) of households to survey, along with a digital map of their survey area. They then took public transportation to village centers, from which they navigated to our respondents via GPS. On average, our survey took 40 minutes, and surveyors collected between 5-9 in a day.

3 Survey results

Data cleaning from the baseline survey remains underway, though key variables have been processed and are presented below.

3.1 Agriculture

Figure 2 gives average long-rains maize yields (tons/ha), fertilizer expenditure (Ksh/ha), and land allocated to maize per household (ha) for farmers in our sample over the past three years[1]. Figure 3 gives average response to fertilizer, estimated via a semi-parametric regression model. Unsurprisingly, fertilizer tends to increase yields, generally with diminishing response at higher applications. As we collect further data on market prices for farm inputs and products, we expect to be able to calculate farm-level profitability, as well as both average and distribution of profitability for farm inputs.

3.2 Randomization checks

75 households were chosen at random to receive a biochar demonstration plot. Figure 4 gives summary statistics over a variety of continuous agricultural and demographic variables, separately for the demonstration plot group and the control group. Table 1 gives summary statistics over several binary variables, again by demonstration plot status. Taken as a whole, most households in our sample farm about 1 acre of land, apply little fertilizer, and receive low yields. Most own 1 or 2 cows, several chickens, and 2-3 acres. Most households have around 6 members, who between them own between zero and two mobile phones, one bicycle, and 2-3 mosquito nets.

Demo plot and non-demo-plot groups are largely comparable – as would be expected from random selection. There are a few minor differences however: demo plot farmers are somewhat more likely to have produced charcoal, have generally used slightly less DAP fertilizer per unit land, have slightly more land devoted to vegetable crops, and have slightly fewer cows. Other differences between groups are not statistically significant, and statistically significant differences are generally small.

The choice of 75 demonstration plots (rather than a larger or smaller number of demonstration plots) was guided by a pilot of our social network survey. In this pilot, we surveyed people from outside of our sampling frame, who our surveyors had visited and collected data from mistakenly. We asked these respondents whether or not they "knew" 50 randomly selected people from our sample, with the probability of 'being asked about' set to the inverse of the distance between the respondent and the potential link. We defined "knowing" somebody in several ways; being acquainted with someone, having talked about farming within the past several months, having loaned or borrowed food or money, etc.

Figure 5 shows linkages (defined here as knowing someone and having seen their land in the past three months) between respondents (red dots) and potential links (black dots) for 25 farmers just outside of our sample. These data – 50 potential linkages each from 25 farmers – allowed us to estimate probability of linkage as a function of distance (allowing that certain people are more or less likely to know or be known than others). Most people know their immediate neighbors, but likelihood of linkage declines with increasing distance. If these patterns hold throughout our dataset, establishing 75 demonstration plots should lead to the median farmer in our sample observing 2 test plots, with about half of the sample observing more and several observing none. This in turn will establish the requisite variation in social learning that we will exploit to learn about its influence on technology adoption.

[1] Maize is the staple crop in the region. Many farmers grew other crops as well, though maize clearly predominated. Data on other crops, and eventually data on changes in yields and land allocation in repose to biochar, will be presented in future reports.

4 Next Steps

4.1 Demonstration plot rollout

With the completion of the baseline survey, randomly-selected demonstration plot farmers were contacted to inform them of their selection, seek their compliance, and determine when we might install the demonstration plot. Timing was generally dependent on when those farmers expected to plant for the short rains, and when their feedstock biomass from the long rains growing season was expected to be dry. Each demonstration plot measures 1/8 acre, and has 4 sections divided between one staple food crop (usually farmers choose maize) and one "other" crop (such as tomatoes or kale), and half with and half without biochar.

When visiting farmers to contact them about the test plots, our field officers demarcated the chosen plot of land (selected for visibility by passersby) with sticks and/or twine. Once the farmer was ready to plant and once dry residues from the previous season were available, we sent one field officer and one casual worker with 3-4 Rutuba kilns to produce biochar from available crop residues, and apply it to the biochar portion of the plot. Plots are then marked with signs advertising the presence or absence of biochar. All other farming decisions are left to the farmer, though farmers commit to providing identical imputs and effort to both the biochar and non-biochar portion of the demonstration plot.

4.2 Introduction of the service model

All farmers hosting the demonstration plots – and many of their neighbors – will observe workers bringing Rutuba kilns to their farms and producing biochar on their land, from their feedstock. Our project's doing so mirrors the rollout of Re:char's "service model." Rather than selling kilns to end-users, Re:char will send workers to produce large amounts of biochar from a recently-harvested and dried field, for a fee. Re:char will continue to sell the Rutuba kiln, but rather than emphasizing them as a tool for use by individual farmers, they will be marketed more as an income-generating device – small-scale entrepreneurs can use them to generate income by producing biochar locally – much as many do by renting-out oxen for plowing for example. One worker can typically char one acre's worth of material in ten days – given agricultural wage labor rates $\sim$Ksh300/day, the purchasing farmer faces a price similar to that for sufficient fertilizer for one acre.

Unlike pitching the Rutuba kiln as a tool for individual farmers to use, the service model has the advantages of divisibility – farmers can buy in increments – and of immediacy. While Re:char has sold $>$1000 units, many early adopters failed to apply the requisite labor to produce biochar on a large scale. Results were therefore not as substantial as they could have been, and viral adoption by tens of thousands of farmers that might have been motivated by large observed yield increases (which are quite possible) was never achieved. From the perspective of our project, the service model removes the risk that those given free biochar trials might not use the kiln sufficiently to realize its benefits. As such, the service model removes a serious barrier to achievement of scale. Once the test plots begin to show results, and before they are harvested, sales pitches given in our project's zones will be based on the service model, rather than direct kiln sales. We may offer kilns for sale before the endline survey (August 2014) – a decision on this will be taken in early 2014.

4.3 Midline survey

The midline survey will be conducted in January or February of 2014, after farmers have had a chance to pay for biochar production or not. Some of these farmers will in turn have been randomly selected to receive subsidies or limited liability offers, which should serve as inducements to buy, in addition to the randomization of demonstration plots. In addition to basic agricultural data, the midline survey will allow us to collect social network data from the full sample of our fully-enumerated farming households. At that point (approximately March/April), we will be in a position to present preliminary results on the efficacy of our interventions in stimulating technology adoption.

4.4 Endline survey

The final survey will take place after the long rain harvest of 2014 (approximately August). This survey will allow us to measure the impact of adoption, as well as secondary adoption by farmers influenced by their neighbor's adoption and/or results. Contingent on funding and other practicalities, we will at that point explore the possibility of offering the Rutuba kiln itself for sale to those who wish either to use it for themselves or as an income-generating tool.

5 Figures

Figure 1: Satellite images of the four zones in which our project is being conducted. Dots indicate surveyed households – red dots indicate households that were randomly selected to receive demonstration plots, blue dots indicate control houses.

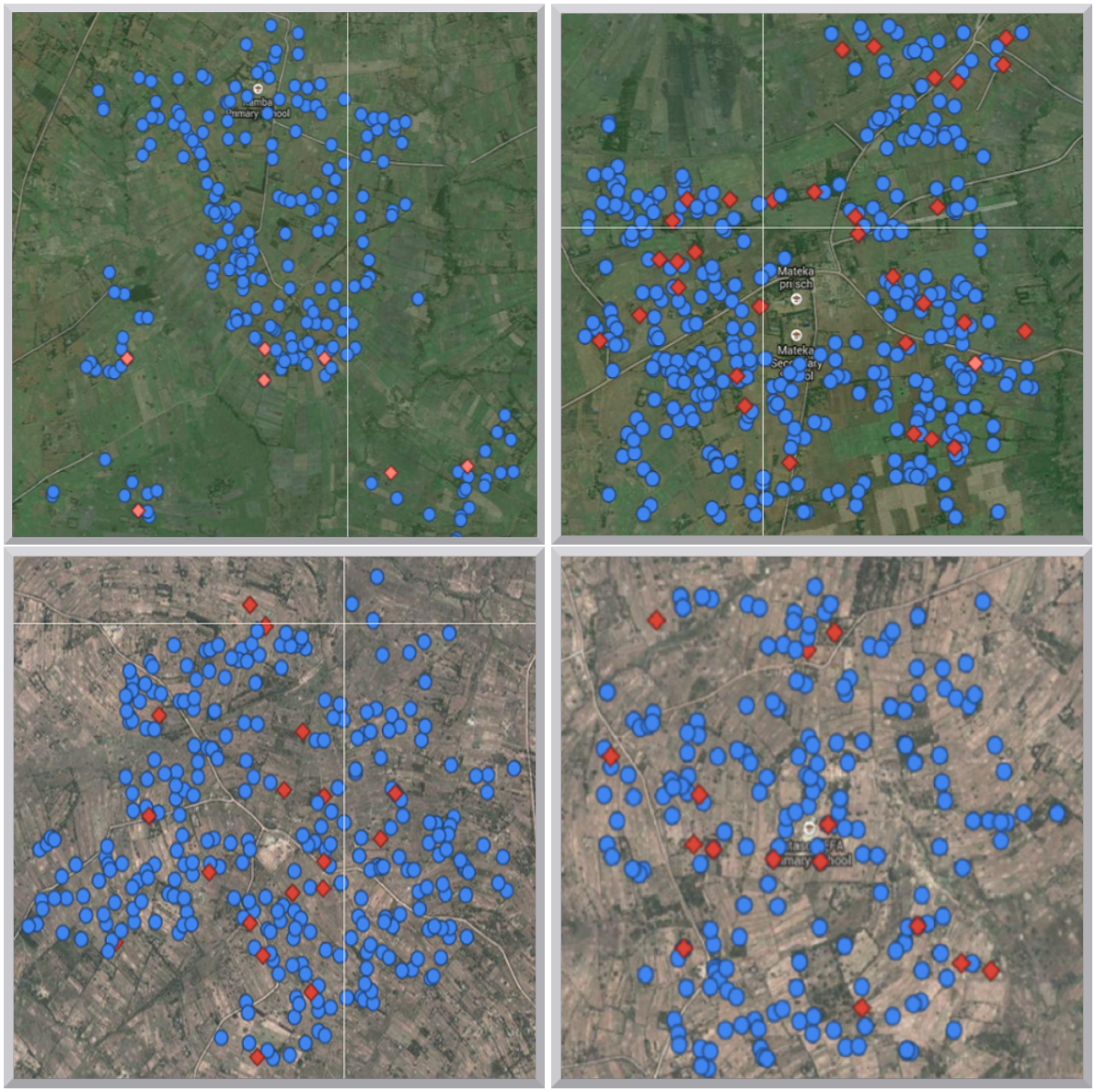


Figure 2: Left: Geographic distribution of maize yields in our four project zones. Darker greens indicate higher average yearly maize harvests per acre (measured in units of 90kg sacks). Center: Geographic distribution of total fertilizer expenditure (in KSH) for maize in our four project zones. Darker blues indicate higher average yearly expenditure over the four most common fertilizer types (DAP, CAN, MAP, Urea). Right: total acres devoted to maize per farmer. Larger dots indicate more land in maize.

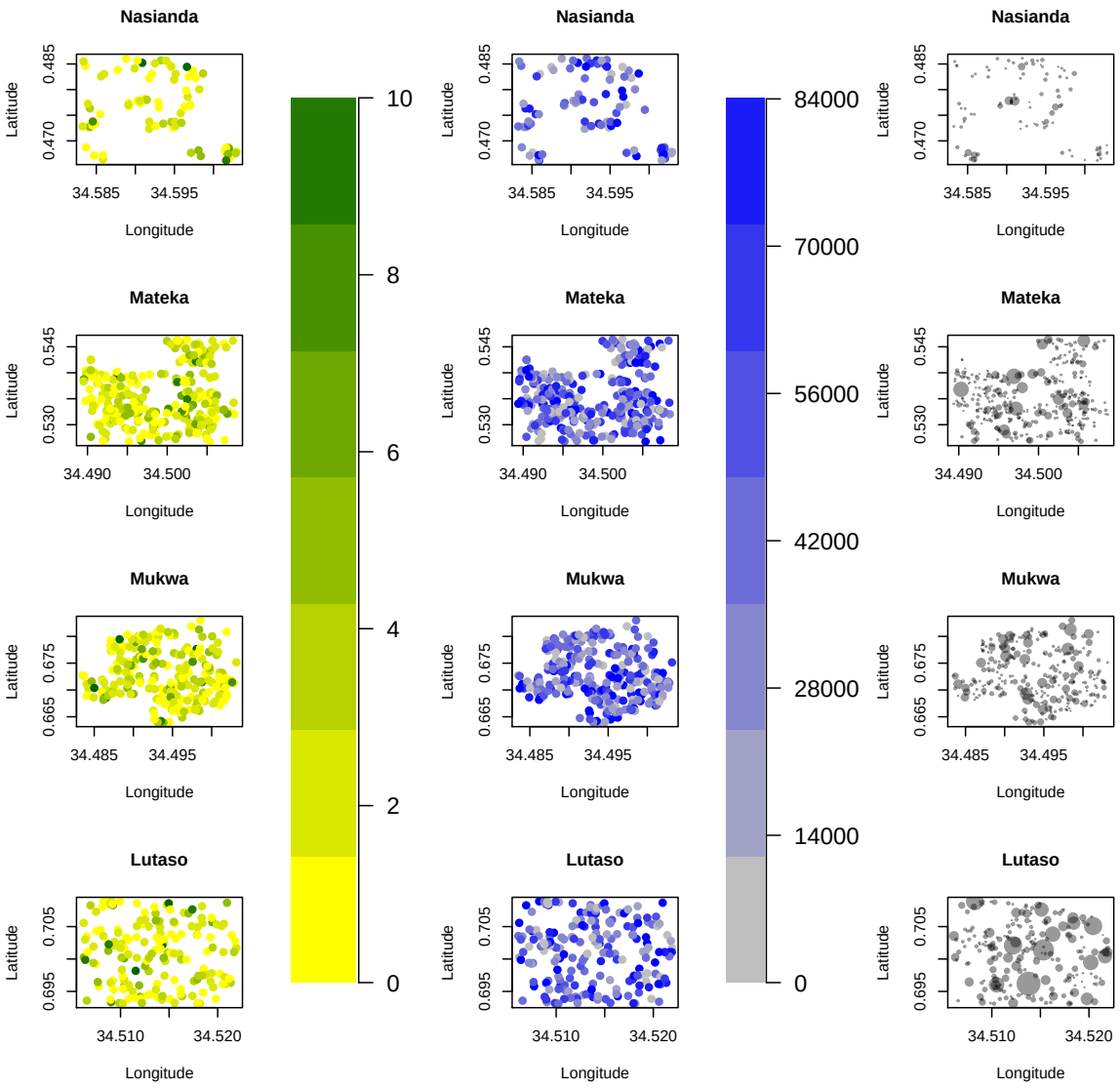


Figure 3: Maize yields modeled as a function of fertilizer addition and land allocation. The upper-left figure gives the distribution of maize yields across the long (black) and short (red) rainy seasons. Dashed lines indicate averages. Other figures give estimated returns to fertilizer (dashed lines indicate confidence intervals, x-axes give log yield increments relative to the estimated conditional mean at zero fertilizer application). Rug plots at the bottom of estimated non-linear functions give the density of observations used to fit the model.

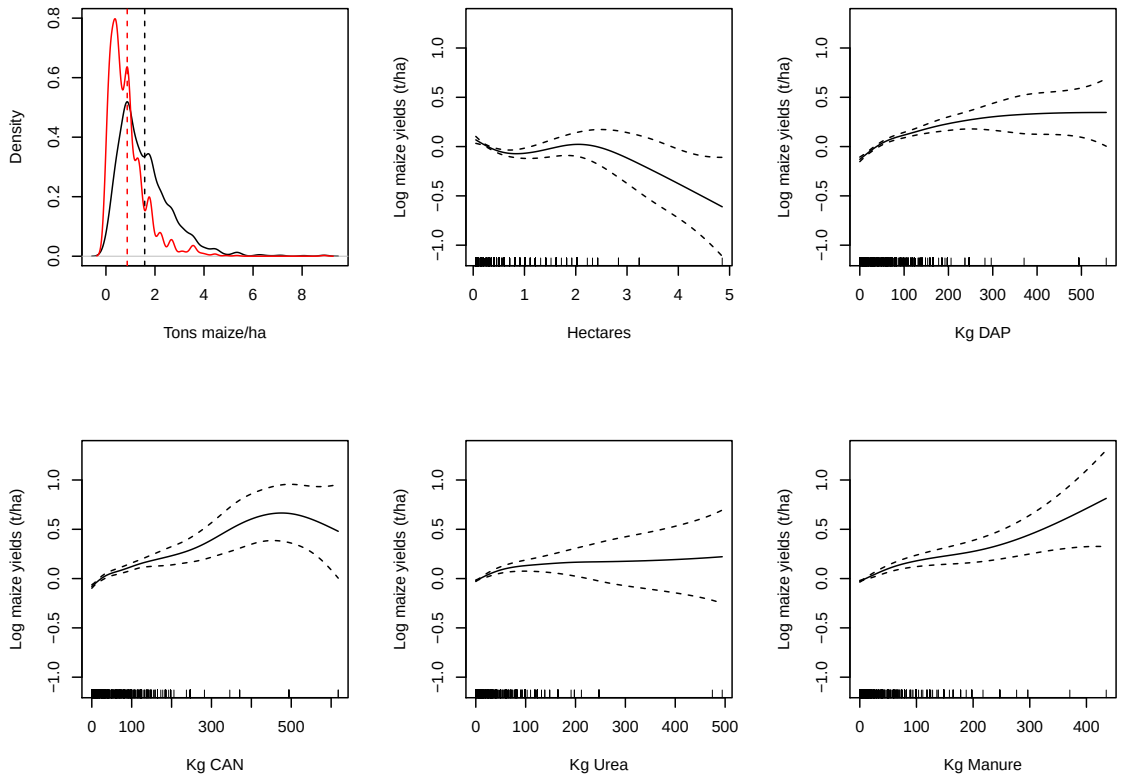


Figure 4: Summary statistics and randomization checks. Blue kernel density plots give distributions of variables for the group without biochar demonstration plots, red kernel densities give distributions for the group with demonstration plots (Purple gives their intersection).

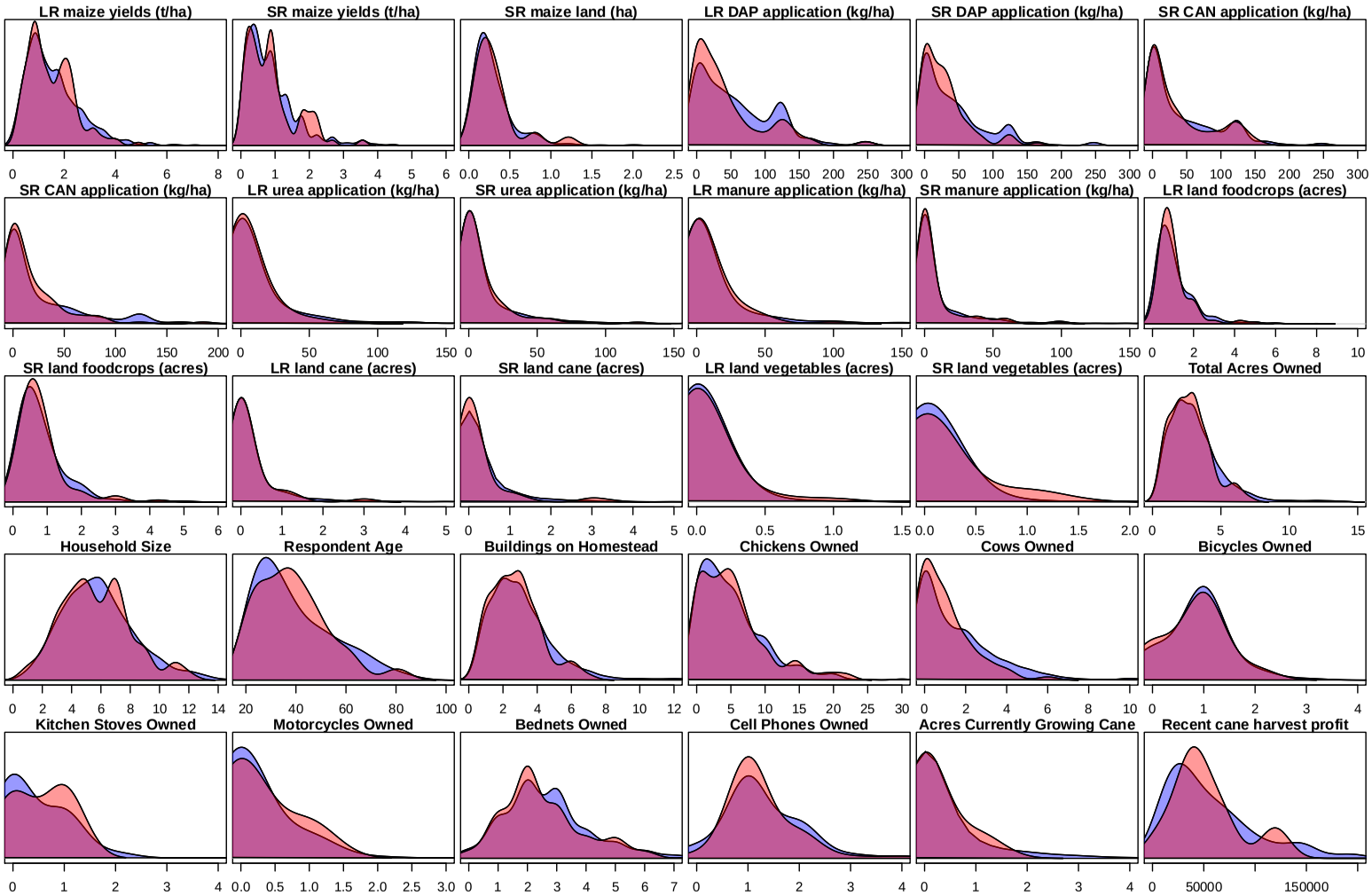
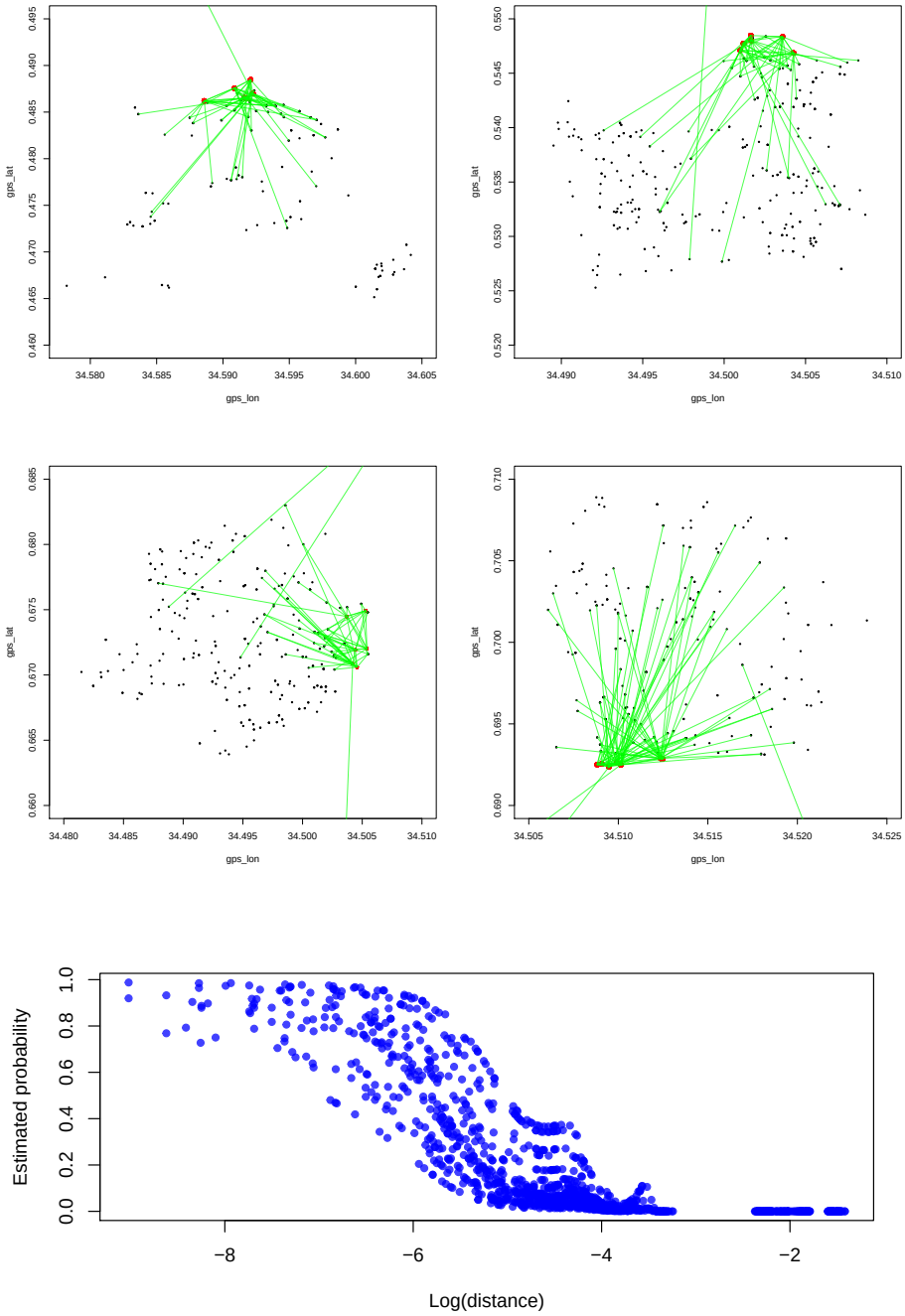


Table 1: Randomization checks for binomial variables. p-values represent probability that coefficients on univariate logistic regressions are different from zero.

Variable	**Proportion w/ demo plot**	**Control propotion**	**p-value**
One Acre Fund membership	.12	.08	.30
House has mud walls	.92	.91	.71
Used charcoal as fertilizer	.053	.049	.86
Produced charcoal	.43	.31	.042
Experienced maize lethal necrosis	.57	.58	.94
Has grown sugarcane	.48	.40	.90

Figure 5: Results of a pilot version of our social network survey, collected from 25 farmers just outside our four project zones. Estimated probability of linkage as a function of distance – which is modeled to include a random component that varies by respondent – is given at the bottom (units = degrees lat/lon).



Scaling Biochar: INVESTING IN SOILS, IMPROVING LIVELIHOODS, AND SEQUESTERING CARBON

Milestone 5: Biochar Test Plots Established & Environmental Mitigation and Monitoring Report

Prepared by: Innovations for Poverty Action

PI: Andrew Crane-Droesch

Grant No.

AID-OAA-F-12-00016

ipa INNOVATIONS FOR POVERTY ACTION

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Scaling Biochar: Environmental Mitigation and Monitoring Report

Andrew Crane-Droesch

15 September 2015

1 Introduction

Pursuant to the requirements of this project's EMMR mitigation plan, this report presents the following:

- Narrative report on biochar soil amendment effect on crops
- Photographs depicting crop development
- Description of our project's adherence to all Kenyan laws and regulations

2 Narrative Report

As of this writing, 76 biochar demonstration plots have been installed on the fields of randomly selected farmers in our project areas. The purpose of these demonstration plots is to inform both the plot hosts, as well as their neighbors, friends, and other social contacts, about the potential gains in crop yields resulting from biochar use. At the end of the present quarter, our project will begin making biochar production services available for sale; we expect to find that those farmers who have more social contacts with biochar demonstration plots will be more likely to invest in the service.

The demonstration plots were installed ahead of planting for the short rains season. Most farmers planted between the end of July and the end of August. Crops in the demonstration plots are therefore still small – none have yet reached anthesis. Anecdotally, farmers report noting better germination performance in the demonstration plots as compared to the zero-biochar control plots (which are located alongside). Farmers have commonly also remarked that the plants in the demonstration plots are "doing well" or are "quite green." We are hopeful that this will lead to substantial harvest differentials at maturity, and ultimately to investment by farmers in biochar production services.

3 Photographs depicting crop development

Implementation of demonstration plots (which consisted of producing biochar on portions of farmers fields and applying it to their soil in planting rows) was completed at the end of August. Once complete, our implementation team commenced monitoring visits to catalog crop development on the demonstration plots. The pictures below provide contrasts between the treatment (biochar) and control (no biochar) portions of the demonstration plots from 6 representative plots:

Figure 1: Demonstration plot example 1: Control (left), vs. biochar (right) applied to maize/bean intercrop.

Figure 2: Demonstration plot example 2: Control (left), vs. biochar (right) applied to maize.

Figure 3: Demonstration plot example 3: Control (left), vs. biochar (right) applied to beans.

Figure 4: Demonstration plot example 4: Control (left), vs. biochar (right) applied to maize.

Figure 5: Demonstration plot example 5: Control (left), vs. biochar (right) applied to maize.

Figure 6: Demonstration plot example 6: Control (left), vs. biochar (right) applied to maize.

4 Adherence to Kenyan Law

Charcoal production is regulated in Kenya. Biochar, while similar to charcoal, is not charcoal: Kenyan law defines charcoal as "wood fuel product derived from carbonization of wood or other plant materials." Due to its friable and powdery structure, biochar cannot be used as a fuel, and thus is not under the jurisdiction of charcoal-related statutes.

A guide to the relevant Kenyan statutes can be found at `www.pisces.or.ke/sites/default/files/The%20Kenya%20Charcoal%20Policy%20Handbook.pdf`, and `http://www.theredddesk.org/sites/default/files/forest_charcoal_rules_2009.pdf`. In general, charcoal-related statutes are promulgated from within the forestry sector, rather than the agricultural sector (within which our project is operating).

Scaling Biochar: INVESTING IN SOILS, IMPROVING LIVELIHOODS, AND SEQUESTERING CARBON

Milestone 8: Demonstration Plot Results, EMMR, Cost-Benefit, and Gender Analysis

Submitted by: Innovations for Poverty Action

PI: Andrew Crane-Droesch

Grant No.

AID-OAA-F-12-00016

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Scaling Biochar: Demonstration Plot Results, EMMR, Cost/Benefit, and Gender Analysis

Andrew Crane-Droesch

31 January 2014

1 Overview

As of this writing, baseline and midline data collection are complete, and our project has shifted to implementation. Biochar demonstration plots were established on small portions of the fields of 75 farmers, and all but one of these has since been harvested and measured. Randomization of sales offers began along with biochar sales in early January, and are ongoing. Sales will continue through to the onset of the long rains – normally in early March – when farmers normally plant. After planting, the project will shift focus to the analysis of data on biochar adoption as a function of randomized demonstration plots, prices, and free trial offers. At harvest – expected in August – we will collect data to enable us to ascertain biochar's impact on yields, complimentary input expenditure and efficacy, and farm-level profitability.

This document serves to address the Jan 31 2014 project milestone, which includes a report on demonstration plot outcomes, an environmental management and mitigation report (EMMR), a mid-term cost/benefit analysis of our project with respect to alternative solutions, and an analysis of gendered impacts of our project. The sections that follow are organized along those themes. In summary, the demonstration plots showed generally strong yet variable results, with benefits correlating with previous yields and with fertilizer application rates. The EMMR is quite similar to the previous one, submitted in September 2013 – we include photos depicting crop development with and without biochar. We use demonstration plot results as a starting point to analyze likely costs and benefits of biochar as compared with other strategies for carbon sequestration and agricultural intensification, though we emphasize that robust results on impact won't be forthcoming until the endline survey, when we will measure the impacts of biochar on the fields of farmers who themselves have adopted. Finally, we present a prospective analysis of likely impacts disaggregated by gender, again with the caveat that these results will be in anticipation of more robust results that will be forthcoming first after all prospective adopters have adopted, and impacts on their fields have been measured.

2 Demonstration plot results

The 76 demonstration plots (one of which was eaten by a cow, leaving 75) consisted of a 1/8 acre parcel of land, to which biochar was applied to half. These halves were divided again into one parcel with either maize or another cereal crop, and another with a crop of the farmer's choice. (Some farmers ignored these instructions and planted only maize, or only another crop.) For each crop on each farmer's plot, we thus have an observation of yields with biochar compared to yields without. Those are presented in figure 1. Results were generally positive, though variable. Maize performed best in response to biochar, though there are more observations for this crop than for others represented. These data are presented spatially in

figure 2. There is little apparent spatial pattern to the distribution of demonstration plot results, while the randomization achieved semi-clustered heterogeneity in demonstration plot placement.

Farmers with demonstration plots were instructed to manage plots with biochar and without biochar identically, but otherwise input and management decisions were left to them. We explore differential response to biochar based on inputs and past yields and fertilizer use via regression (figure 3), in which the response ratio (the natural logarithm of the ratio of biochar yields to control yields) is set equal to a function of these variables. Positive response to biochar is associated with higher levels of CAN (calcium ammonium nitrate) and DAP (di-ammonium phosphate) fertilizer, and associated with lower levels of urea. This suggests, as we expected, that biochar may improve response to inorganic fertilizers. Positive response is only weakly (and not significantly) correlated with previous yields or fertilizer use. To the extent that these variables serve as proxies for soil quality and/or poverty, we are somewhat surprised to find little association.

For the most part, farmers report being satisfied with the results of the demonstration plots, and we anticipate higher takeup of biochar for sale among these farmers, and among those of their neighbors and social contacts who observed the results that we document here.

3 EMMR

Pursuant to the requirements of this project's EMMR mitigation plan, this section presents the following:

- Narrative report on biochar soil amendment effect on crops
- Photographs depicting crop development
- Description of our project's adherence to all Kenyan laws and regulations

3.1 Narrative Report

As of this writing, 76 biochar demonstration plots have been installed on the fields of randomly selected farmers in our project areas, and all but 1 has been harvested. The purpose of these demonstration plots was to inform both the plot hosts, as well as their neighbors, friends, and other social contacts, about the potential gains in crop yields resulting from biochar use. We are now beginning to make biochar production services available for sale; we expect to find that those farmers who have more social contacts with biochar demonstration plots will be more likely to invest in the service.

The demonstration plots were installed ahead of planting for the short rains season. Most farmers planted between the end of July and the end of August, 2013. Yields from demonstration plots were analyzed in the previous section.

3.2 Photographs depicting crop development

Implementation of demonstration plots (which consisted of producing biochar on portions of farmers fields and applying it to their soil in planting rows) was completed at the end of August. Once complete, our implementation team commenced monitoring visits to catalog crop development on the demonstration plots, and eventually to harvest them. The pictures below (figures 4,5 & 6) provide contrasts between the treatment (biochar) and control (no biochar) portions of the demonstration plots from 3 representative plots.

3.3 Adherence to Kenyan Law

Charcoal production is regulated in Kenya. Biochar, while similar to charcoal, is not charcoal: Kenyan law defines charcoal as "wood fuel product derived from carbonization of wood or other plant materials." Due to its friable and powdery structure, biochar cannot be used as a fuel, and thus is not under the jurisdiction of charcoal-related statutes.

A guide to the relevant Kenyan statutes can be found at `www.pisces.or.ke/sites/default/files/The%20Kenya%20Charcoal%20Policy%20Handbook.pdf`, and `http://www.theredddesk.org/sites/default/files/forest_charcoal_rules_2009.pdf`. In general, charcoal-related statutes are promulgated from within the forestry sector, rather than the agricultural sector (within which our project is operating).

4 Mid-term cost/benefit analysis

It is well-established in the agronomic literature that biochar can improve crop yields, particularly in the sorts of soils that characterize our Western Kenyan context. Thus, the results from our demonstration plots are unsurprising and indeed, relatively uninteresting. What is not well-established are dynamics of biochar adoption by smallholder farmers, nor the effect of biochar adoption on farmer welfare, which will be mediated both by biochar's agronomy and farmer behavior. Given that we don't yet have data on farmer behavior with regard to biochar adoption (we are collecting it now) or the consequences of this behavior (we will collect those data in August), we cannot give a definitive answer to the question: "is biochar 'worth it"' in economic terms.

We can however give a preliminary answer. Our general approach is to first estimate biochar's agronomic benefit (as mediated by complimentary fertilizers), then estimate baseline response to fertilizer absent biochar, then simulate the effects of biochar adoption at a variety of biochar prices. These in turn lead to a range of expected profitabilities depending on farmer characteristics, giving us a distribution of likely impacts at a variety of biochar prices, ranging from prices at which sales of biochar are profitable, to low prices which would require subsidies.

We begin by estimating a statistical model representing the results of the maize demonstration plots as a function of the complimentary inputs added and previous maize yields and fertilizer additions:

$$RR = \alpha + f(DAP) + f(CAN) + f(Urea) + f(PrevYield) + f(PrevFert) + \varepsilon \tag{1}$$

where RR is the response ratio, defined as the logarithm of the biochar plot yield divided by the control plot yield. Results are given in figure 3, and provide estimates of likely response – in terms of change from baseline yields – to biochar conditional on fertilizer application. Response to biochar is increasing in CAN and DAP use, and slightly negative, though not significantly so, in previous yields, fertilizer use, and urea use. We then estimate a fixed-effects regression model representing maize yields as a function of farmer-level fixed effects and fertilizer expenditure, using data collected in the midline survey, on agricultural inputs and outputs over the past three years:

$$yield_{it} = \alpha_i + f(FertExpend_{it}) + \varepsilon_{it} \tag{2}$$

Results are given in figure 7 – on average, yields are increasing in fertilizer, though with declining marginal yields at higher application rates.

To estimate the effect of biochar on agricultural profits at a given price, we first define $ProfDif \equiv BiocharProfit - BaselineProfit$. Baseline profit is defined simply as average yields per-farmer, multiplied by the market

price of maize, less the cost of their average fertilizer expenditure, over the three years for which we have data. Biochar profit is defined as:

$$BiocharProfit_{ip} = \widehat{yield}_{ip} * e^{\widehat{RR}_{ip}} - FertExpend_{ip} - BCPrice_p \tag{3}$$

where i indexes farmers and p indexes biochar prices. The highest biochar prices that we consider is KSh5000/acre, or $145/ha, which is approximately double our project's break-even point for sold biochar (and which also constitutes the maximum price which a farmer in our sample may randomly draw). The term $\widehat{yield}_{ip}$ is calculated as expected yields for farmer i at their normal fertilizer expenditure, minus the cost of biochar. The term $\widehat{RR}_{ip}$ gives the expected response ratio by which biochar modifies expected yields, which varies with biochar price by changing the amounts of fertilizer (which mediate biochar's efficacy) applied with biochar, such that average agricultural expenditure remains unchanged. Farmer who normally spend less on fertilizer than $BCPrice_p$ are modeled as not adopting biochar, as are those for whom our model would suggest that it would be unprofitable. Those results, for a range of biochar prices, are given in figure 8.

For most farmers, biochar at the highest price that we consider would not be profitable – biochar becomes profitable for the median farmer at approximately $40/ha (at an application rate of approximately 500kg/ha). This is almost certainly an underestimate of biochar's profitability however – given that biochar's benefit in soil has been shown to be durable over a number of years, and given that figure 8 represents potential gains for only one season.

The region of the figure to the right of the vertical line represents prices which would require subsidies, and the dotted green line indicates the ratio of the subsidy expenditure to the benefit derived by farmers. While small subsidies are very cost effective in terms of return on investment, large subsidies – all the way to giving biochar away completely for free – generate more gain than they cost to provide.

We compare the benefit/cost of biochar to the benefit/cost of subsidizing inorganic fertilizer. We approach the analysis similarly – for each biochar pricepoint, we take the associated subsidy (defined as the sum of the subsidy payments for those who avail themselves of them), and distribute that money to all farmers in our sample in the form of extra fertilizer (which all adopt, given that the benefits we model are strictly increasing). Benefits are more homogenous in this scenario, given in figure 9.

Comparing the two (by subtracting the distributions from one another), we find that subsidized fertilizer is better for more farmers in the short term than subsidized biochar, though a substantial portion of our sample would be better off with subsidized biochar (figure 10). Short-term benefits are misleading however. If, for example, biochar were to be subsidized for one season, and many farmers adopted biochar, those farmers would get direct benefits during the next season from the biochar which they had added in the past, at zero present cost. Furthermore, their inputs of costly fertilizer would likely be more effective than they would otherwise be. However, we lack Kenya-specific data on multi-year response to biochar, and are thus unable to quantify these prospective benefits at this juncture. Absent subsidies, biochar remains beneficial for a substantial fraction of our sample, even in the short term.

Up to now we have been concerned only with biochar's agronomic benefit. However, biochar also provides a public good in the form of carbon sequestration. At the application rates that we are using – approximately 500kg/ha – we assume conservatively that half of this mass is carbon, and that half of this carbon is "stable[1]" – we are applying 125kg of stable carbon per hectare. Figure 11 gives amounts of carbon sequestered per dollar social cost (which is negative, indicating social benefit), and per farmer. Total amounts of carbon are modest on a per-farmer basis, but benefits per ton of carbon are quite large.

[1]Biochar turnover time is long, yet poorly constrained. Recent studies give estimates anywhere between hundred to tens of thousands of years.

Total mitigation benefits are modest – scaled to reach 25% of Kenya's 58 million agricultural hectares, our assumptions suggest that biochar would sequester 600,000 tons of carbon per year – equivalent to the annual emissions of approximately 46,000 average American households, or 1.3% of Kenya's greenhouse gas emissions. However modest these mitigation benefits may be, their negative cost improves their value relative to several costlier solutions. Furthermore, these benefits represent carbon removed from the atmosphere, rather than avoided emissions. As such, they are more effective, given that only approximately 45% of emitted carbon remains in the atmosphere (the "airborne fraction"), and, if humanity is ever successful in attaining carbon neutrality (with respect to the airborne fraction), these gains would represent carbon removed from the atmosphere – reversing the buildup of carbon in the atmosphere, however slowly.

5 Gender analysis

It is well-recognized that many development interventions have differential impacts on men and women. In many parts of sub-Saharan Africa, woman are responsible for a large portion of farm work, but yet have little influence over agricultural decisions. As our project moves through implementation, we plan to analyze heterogeneity in uptake rates by gender of the head of the household.

This data is currently being collected, as biochar is beginning to be offered for sale for the upcoming long rains season. Much in the same vein as the preceding sections, we offer a prospective analysis of gendered impacts – taking the estimated prospective benefits of biochar adoption at a variety of prices, and disaggregate them by the gender of the head of the household. Those estimates are presented in figure 12. Under the assumptions guiding this prospective analysis, there is little difference in prospective benefit between the 851 male-headed and 100 female-headed households[2] – the distributions overlap substantially. Furthermore, agricultural summary statistics – when disaggregated by the gender of the head of the household – also show little difference by gender (figure 13).

Note that prospective benefit calculations assume that farmers will adopt biochar if its apparent costs are exceeded by its benefits – a dubious assumption in the real world. We look forward to collecting data which will enable us to measure gender difference in adoption propensity.

6 Figures and tables

[2]Female-headedness was operationally-defined as households where the female respondent – all respondents were those responsible for agricultural decisions in the family – was either unmarried or a widow.

Figure 1: Results on biochar demonstration plots. The diagonal line demarcates negative from positive contrasts. Yields per plot converted to ton/ha equivalent.

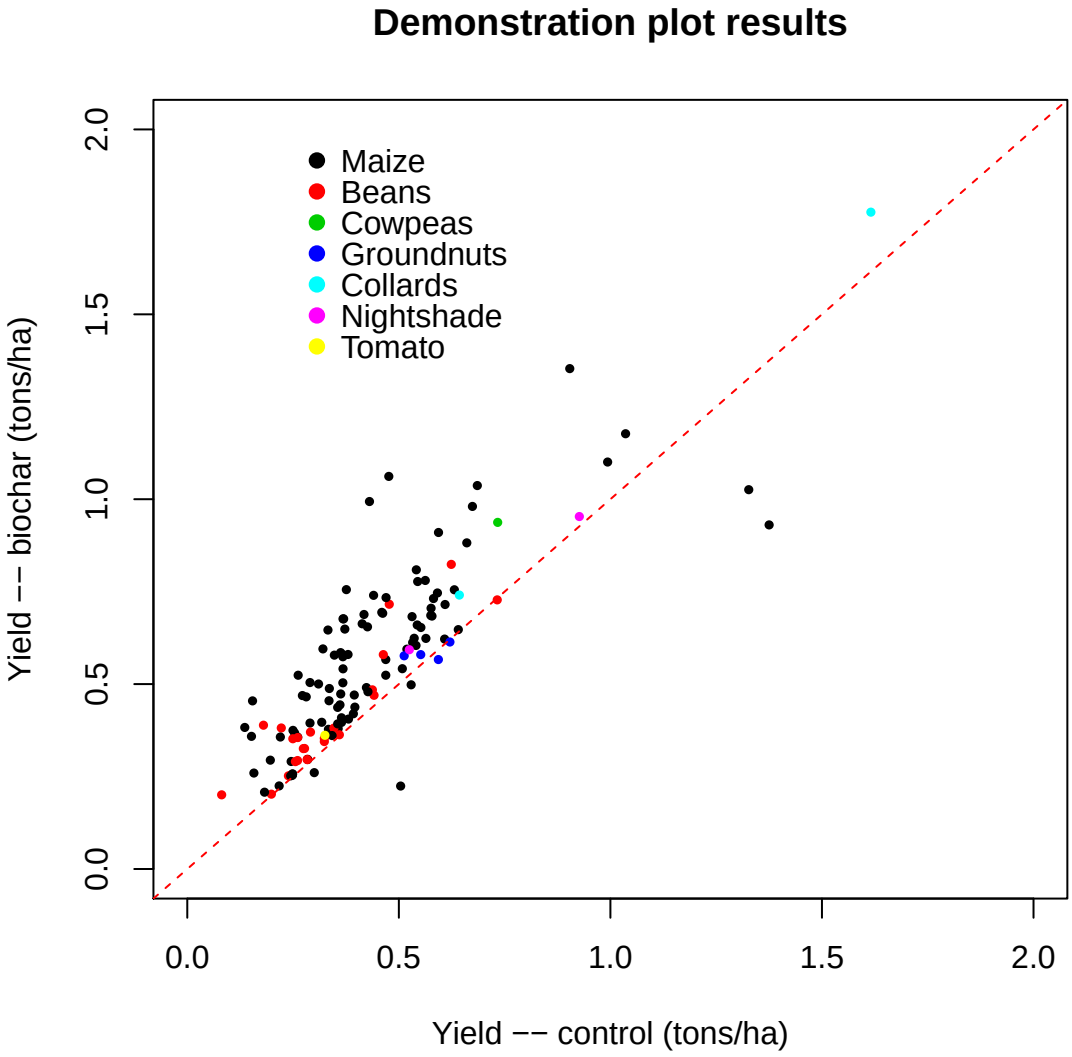


Figure 2: Results on biochar demonstration plots, presented spatially. Small dots indicate respondents, large semi-transparent dots indicate demonstration plots. Relative transparency in green (red) dots gives the magnitude of positive (negative) results in relative terms. Results subset to maize.

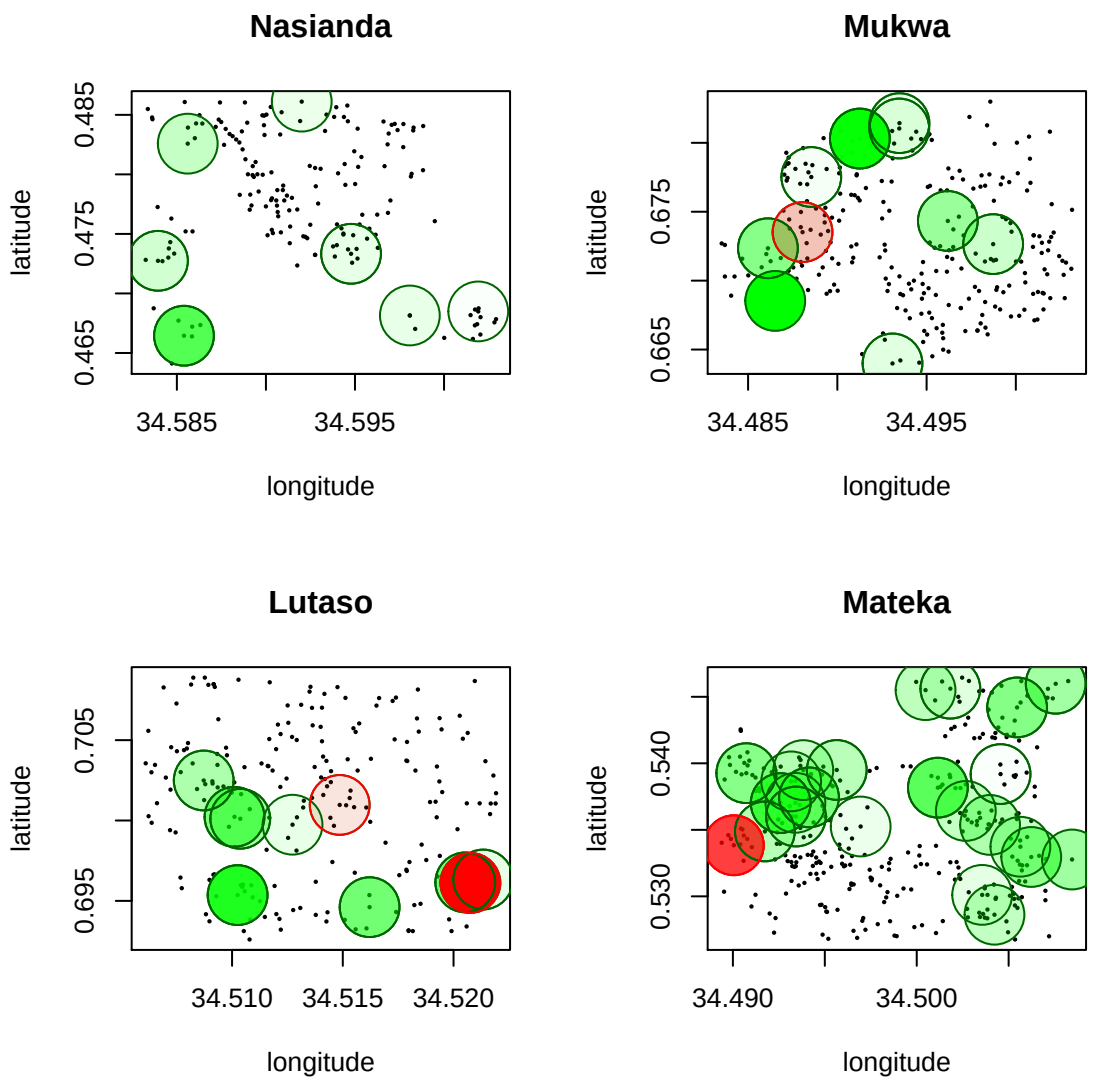


Figure 3: Regression results modeling response ratio (ln(biochar yield/control yield)) on maize demonstration plots as a function of DAP fertilizer, CAN fertilizer, Urea fertilizer, previous average crop yields, and previous average fertilizer use.

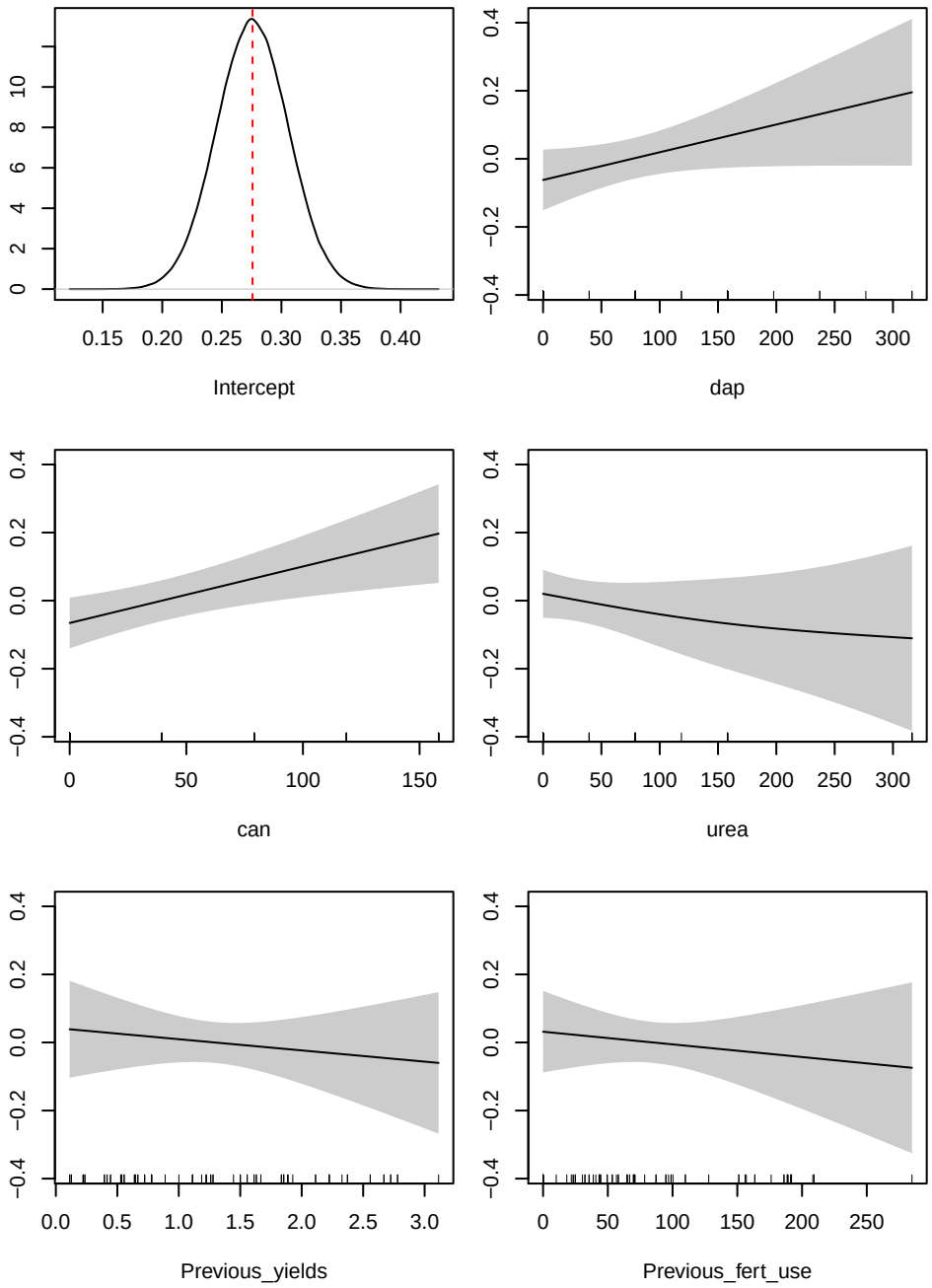


Figure 4: Example of a demonstration plot; with biochar above, without below. Note in this picture enhanced vegetative growth in the biochar plot.

Figure 5: Example of a demonstration plot; without biochar above, with below. Note in this picture purple streaks on leaf – an indication of poor phosphorous uptake, which can inhibit grain filling. Note the full cob on the plot with biochar.

Figure 6: Example of a demonstration plot; without biochar above, with below. Note thicker vegetation and thicker maize cobs on the demonstration plot, as compared to the control.

Figure 7: Estimates from equation 2. The left figure gives estimates of farmer-level fixed effects, and right figure gives estimates of the effect of fertilizer on maize yields. Estimates of yields for a given farmer sum the estimate farmer effect and the effect of fertilizer at a given level.

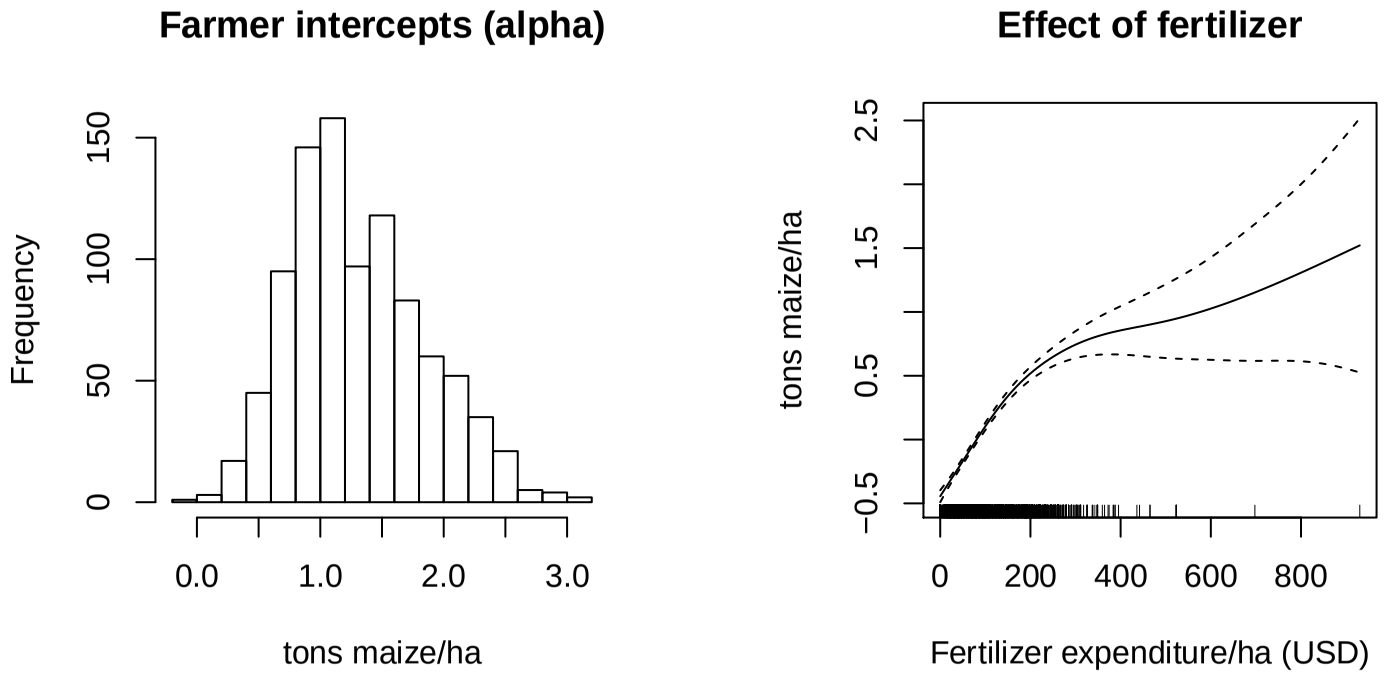


Figure 8: Costs and benefits of biochar at a variety of subsidies, assuming a base price of Ksh5000/acre, or ∼$145/ha. Semi-transparent blue points indicate per-farmer projected differences between the no-biochar baseline, and an alternative scenario wherein the farmer uses biochar at a price indicated on the x-axis. All costs to the right of the vertical line indicate prices at which biochar should be profit-making, not requiring subsidies.

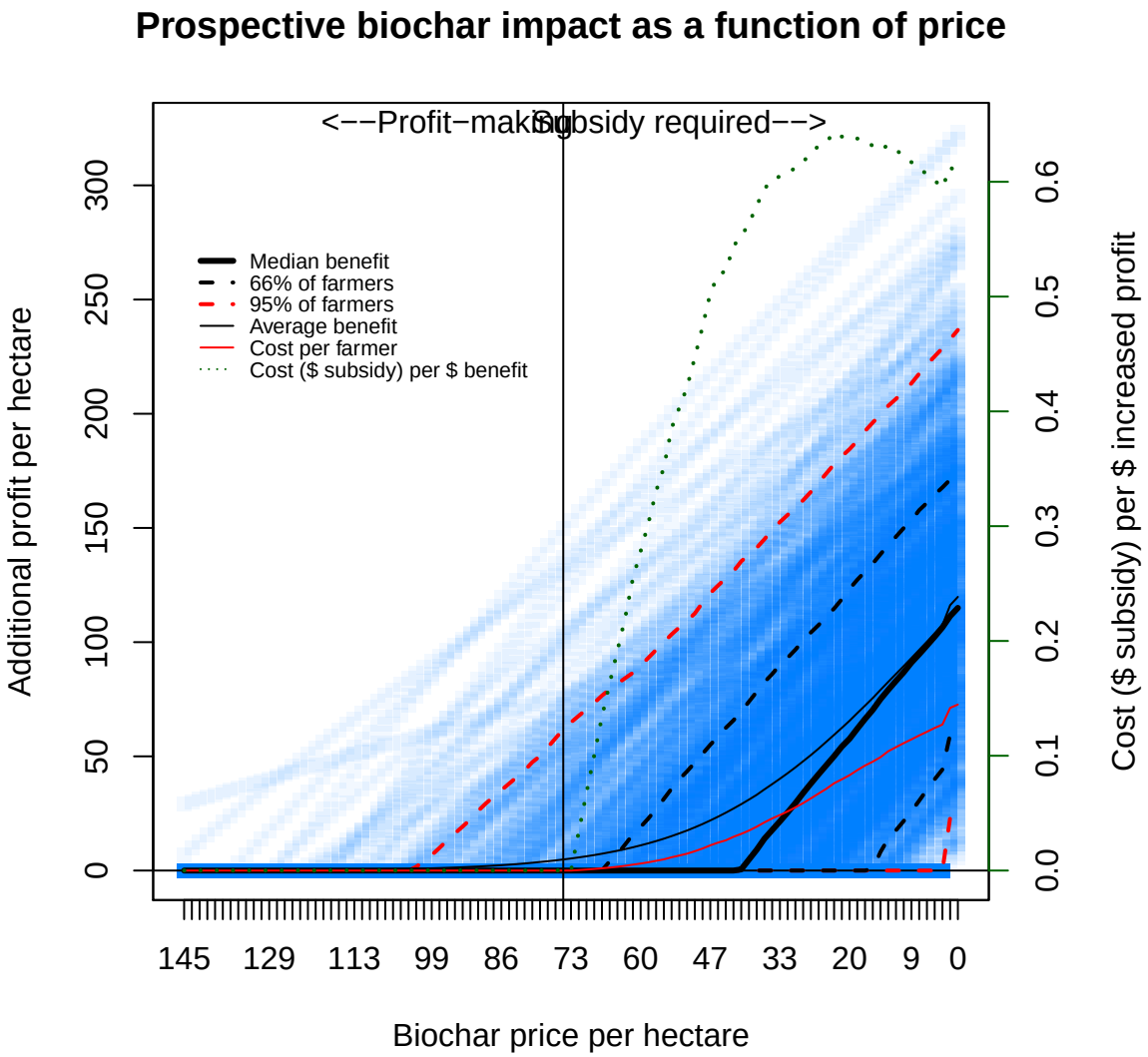


Figure 9: Benefits and costs under a scenario under which fertilizer is subsidized using money equivalent to the subsidies spent on biochar in the biochar scenario. Semi-transparent blue points indicate per-farmer projected differences between the baseline scenario and an alternative scenario wherein the farmer uses extra subsidized fertilizer (defined by the equivalent of the biochar subsidy). Flat response on the left side of the curve indicates areas where biochar sibsidies are zero due to biochar's profitability in those regions.

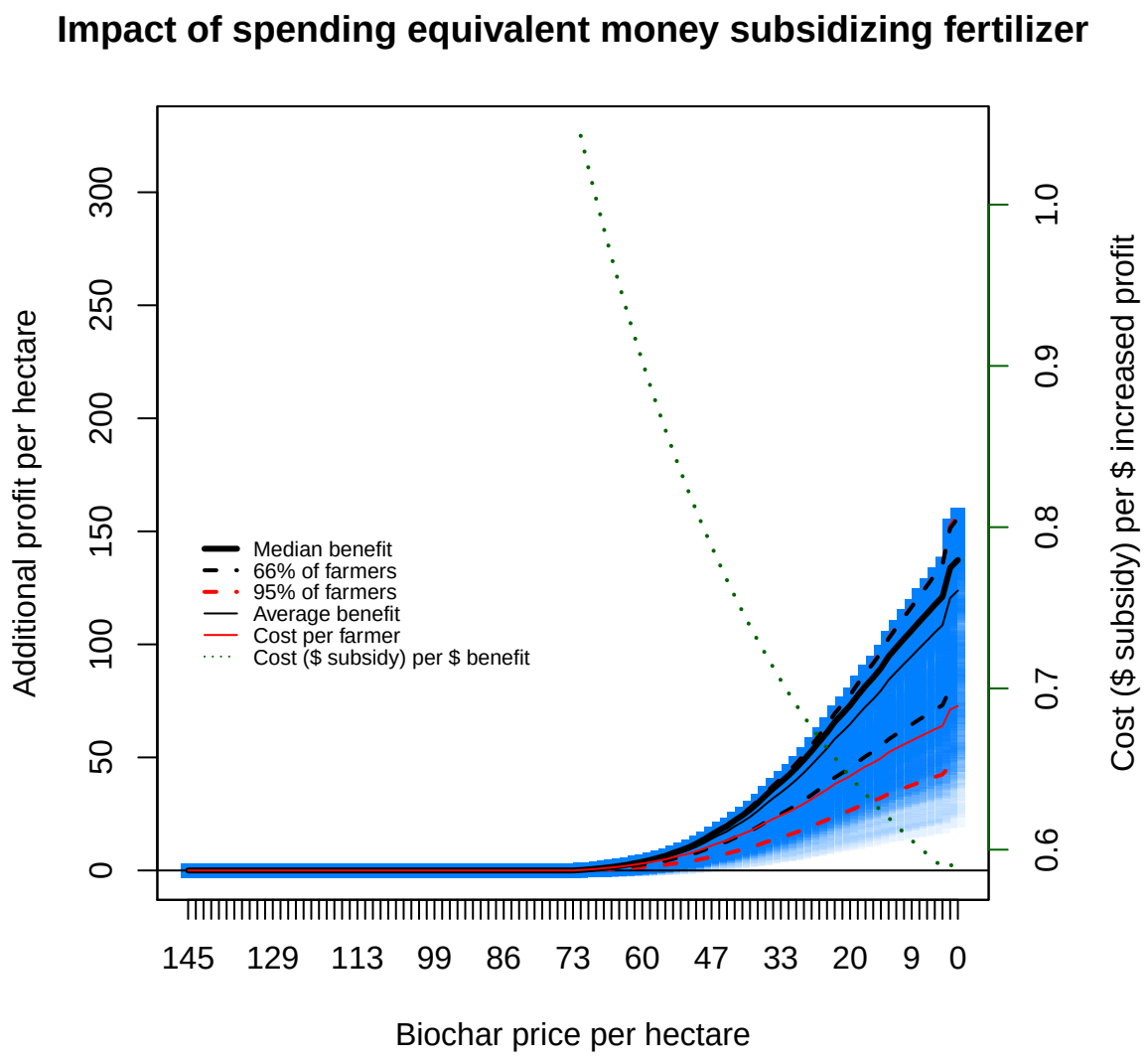


Figure 10: Comparison of benefits of subsidized biochar versus subsidized fertilizer. The are to the left of the vertical line represents unsubsidized, profit-making biochar. The y-axis gives the difference in additional profit between the two scenarios. Fertilizer subsidies are set equivalent to biochar subsidies, and are therefore zero to the left of the vertical line.

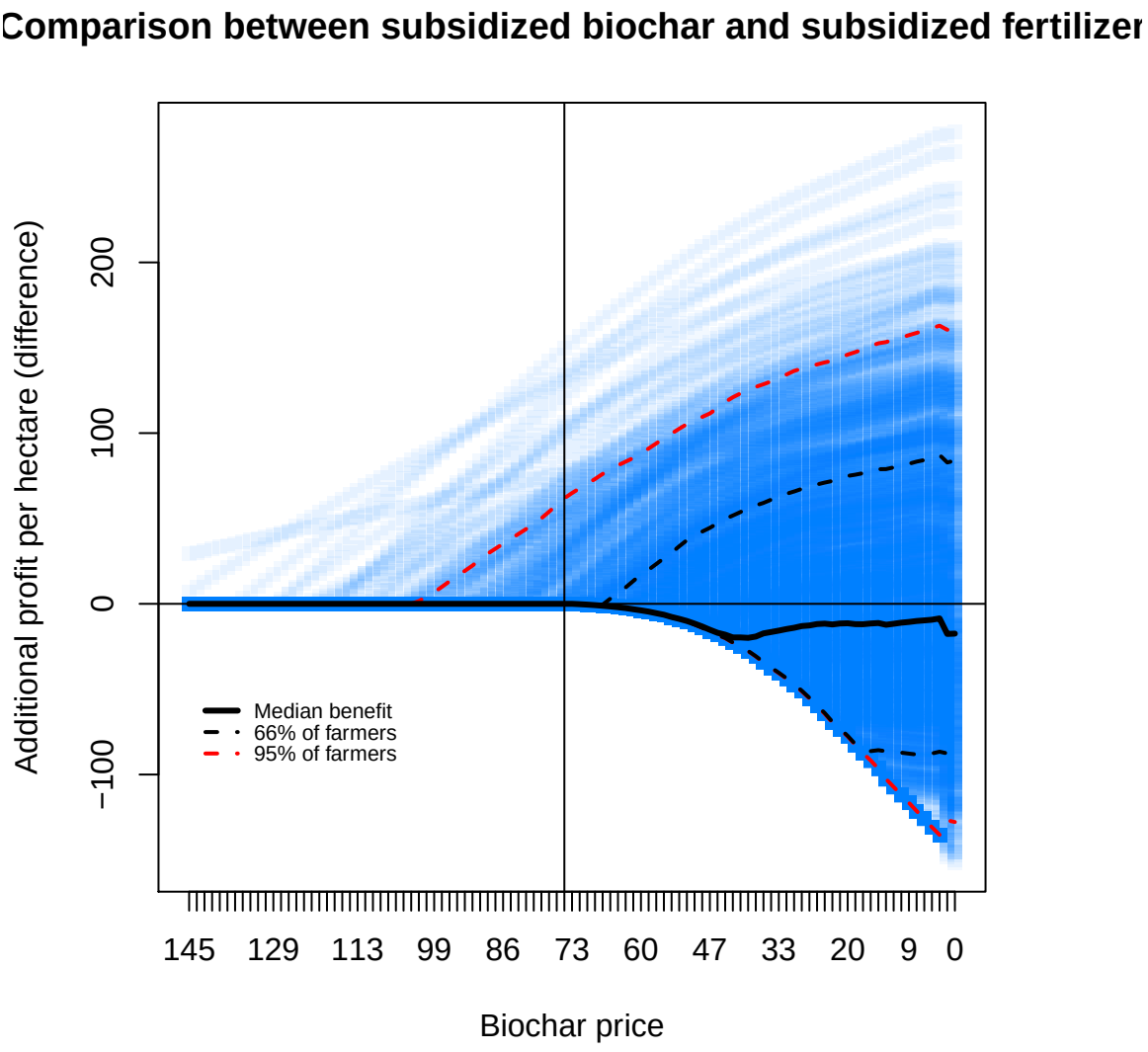


Figure 11: Social and program costs of carbon sequestration via biochar. Left figures give costs per ton of carbon, right figures give total carbon per farmer per year. Upper figures give social costs (defined as program costs minus benefits, lower figures give program costs only).

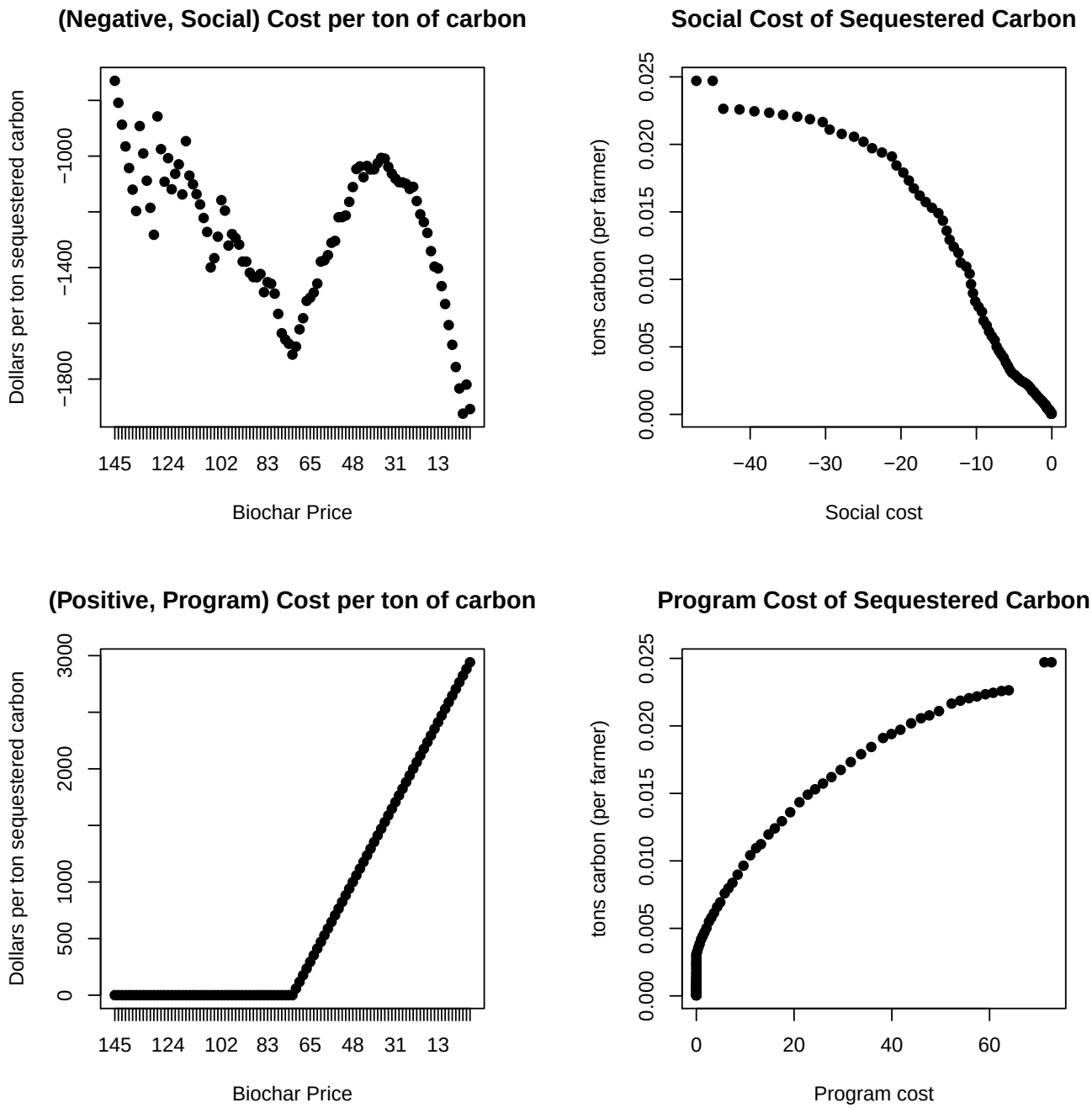
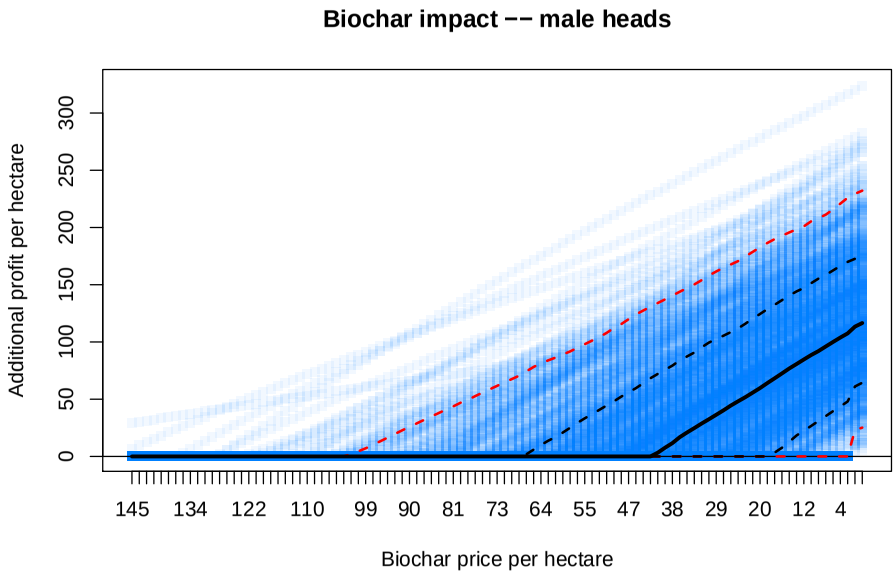


Figure 12: Prospective biochar benefits disaggregated by gender of head of household.



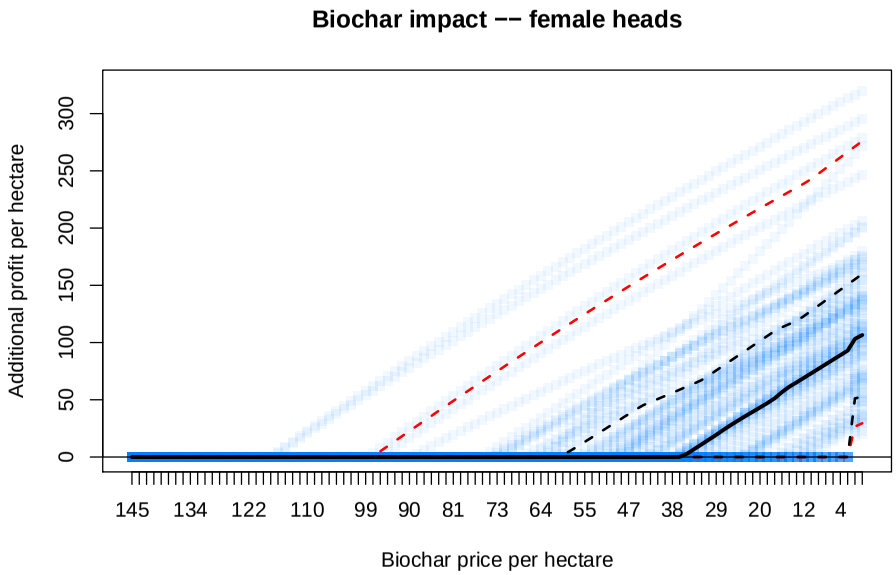
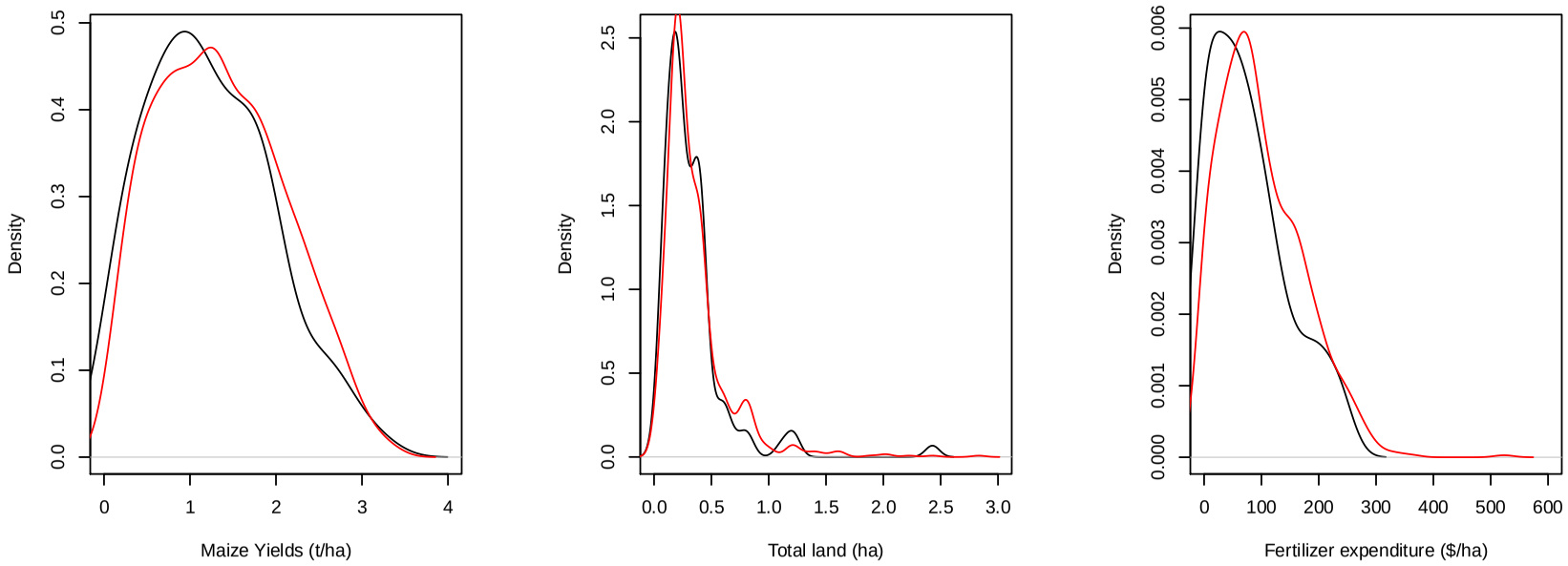


Figure 13: Agricultural summary statistics – density plots by gender (female-headed households in black, male-headed households in red).



Scaling Biochar: Report on Midline Survey, and Preliminary Adoption Results

Andrew Crane-Droesch

April 2014

1 Overview

This report covers our midline survey and first wave of biochar sales, roughly from January to April 2014. The midline survey followed up with those surveyed at baseline, collecting agricultural information (inputs, yields, etc.), as well as data on the social networks of farmers. Following the baseline survey, in the runup to this year's long rains agricultural season, we began to offer biochar for sale to farmers in our sample. As described in the sections below, farmers received random offers, varying in price as well as varying in whether or not payment would be expected up front, or at the end of the season. In addition, we had previously randomized provision of biochar demonstration plots, creating heterogeneity in the degree of potential social learning between farmers about the effects of biochar.

Results of sales were disappointing. While demonstration plots showed that biochar led to strong increases in yields and some enhancement in the efficacy of fertilizer (see previous report), farmers showed very little willingness to pay for biochar. While most of the farmers offered free trials of biochar accepted the offer, only a handful of our sample without the free trials purchased biochar. Those that did purchase biochar were largely those that received the lowest possible price that could have been obtained via the randomization of the prices.

While results from the recent planting season are discouraging, we are open to the prospect that wide-scale takeup of the free trials may serve as an even-broader force to promote social learning about the benefits that biochar can provide; effectively serving as demonstration plots in much the same way as we expected from the previous season's demonstration plots, and thereby prompting uptake. Current activities are largely aimed at preparing for the runup to the coming short rains planting season.

2 Activities

2.1 Midline Survey

The midline survey took place during January and February of this year. As with the baseline, we collected our surveys using Open Data Kit software on tablets, facilitating data collection.

Sample attrition was a significant problem in the midline survey. While we collected data on 1116 households in the baseline survey, we were only able to re-survey 951 of them. 26 of these we've confirmed have moved away, while the others may either have moved away (temporarily or permanently), or were otherwise

unable to be found, even after repeated attempts to call them, catch them at home, or ask their neighbors about their whereabouts.

The survey focused on both agricultural and social network data. The former was quite similar to the data collected in the baseline survey. The latter focused on eliciting the links of the social networks binding people together in our sample, which we're interested in because of our focus on determining the role that social learning can play in technology diffusion.

Given that it is possible that any given person knows any other given person, the total number of potential social network links is N^2, where N is our sample size of 951. It is clearly impractical to ask about that many potential links. We therefore performed a stratified sample of potential links, using the following algorithm:

- For each household in our sample, calculate the distance between them and all of the other households in our sample.
- For each household, randomly select 75 potentially linked households, with the probability of selection being proportional to the inverse of the distance between the two households.
- Generate a sheet of potential links for each household in our sample, containing the names of the adults, their nicknames, and their location.

We used these sheets for the social network component of the survey, with each farmer asked whether they know people in the referenced household, along with how they know them; e.g.: whether they had recently talked about farming, whether they are related, whether they had seen the crops of the other, whether they are part of the same church/mosque, etc.

2.2 Biochar production

With regard to biochar provision, our project's original plan was to directly sell biochar production kilns to farmers. We changed this several months ago to the sale of the service of biochar production, whereby we would go to the fields of farmers with kilns and produce biochar on their land from their crop residues. However, we quickly discovered that this would not be practical in the runup to the long rains season, because most farms had very little residue available from which to make biochar. The most recent harvest had been in November; by February, most remaining residue had been used as cattle feed, burnt, or was otherwise gone.

We therefore undertook to produce large bags of biochar for sale, using recently-harvested sugarcane fields in the vicinity, and compensating those farmers for their material. Since sugarcane production is far less seasonal than maize, there is generally a year-round supply of cane trash, from which biochar can be produced. This produced biochar was bagged and transported to rented storehouses in the vicinity of our project areas, for ready transport to the fields of biochar-adopting farmers.

2.3 Randomization and Biochar sales

We set the base price of biochar to be KSh1,250 per 1/4 acre, on which we applied 2 20kg bags of biochar (of the same volume as a 90kg sack used for maize). This price was chosen conservatively, to be approximately proportional to the cost of recommended inorganic fertilizer application – 50kg of DAP and 50kg of CAN, which is the commonly recommended fertilizer application rate per acre in the area, will generally cost between KSh5000-6000.

Table 1: Random biochar prices received as offers by farmers in our sample.

Price per 1/4 acre (KSh)	100	250	350	500	600	750	900	1000	1100	1250
Number receiving offer	29	41	55	60	75	83	88	96	99	272

While the base prices was KSh1,250, farmers faced randomly-varying prices below this amount. We conducted the randomization by printing a number of offer sheets, each with a randomly selected price and a 25% chance of including a free trial. The prices were selected from a distribution in which higher prices were more likely than lower prices, reasoning that fewer low prices than higher prices would be necessary to elicit the location of the demand curve at that price, if adoption at low prices was to be disproportionately likely.

These offer sheets were then placed into blank envelopes, and taken by surveyors into our project areas. Field officers explained to respondents that biochar would be available for sale, give a short description of its benefits, asked whether they had seen any of the demonstration plots, and finally asked farmers to choose from a number of blank envelopes. They then opened the one chosen, and the surveyor explained to them its contents, how the free trial worked if they got one, etc.

Of the 951 farmers that we surveyed in the midline, we were able to locate only 900 of these to receive randomized biochar sales offers. The prices that these received are summarized in table 1. Of these, 231 received free trial offers. Under the free trial, farmers recieve two bags of biochar (applied to their soil by our workers) for free, with the option to repay – at the randomly-allocated price – ater seeing the results at next harvest. Those farmers not repaying would be barred from purchasing biochar in subsequent seasons.

This offer randomization was largely concluded by March, by which point the rains had not yet begun. Many farmers expressed that they would like us to return to fulfill their orders for biochar at the onset of the rains. As the rainy season began to establish itself through March and into April, we kept in contact with farmers by sending mass-SMS messages to those with phones, and doing household visits to those without phones. As orders came in, a team of workers applied biochar to the fields of those adopting, again using 2 20kg bags per 1/4 acre.

3 Results

Uptake was generally poor. Of those 231 who received free trial offers, only 149 requested a free trial of biochar. Of those who did not receive a free trial, only 13 farmers adopted biochar, at an average price of KSh257.7. We are currently in the process of cleaning and analyzing these data in order to determine how adoption correlated with the randomly allocated prices, and how this was mediated by social network exposure to biochar. However, we are not optimistic about finding a clear signal with so few adopters.

4 Next Steps

As mentioned above, analysis of midline data is ongoing.

In the meantime, 164 farmers have received biochar, and have maize growing on amended plots. If results on these farms are similar in magnitude to those that we saw in the demonstration plots last November and December, then we will have effectively "re-seeded" our sample with new demonstration plots. It is possible that demand will grow in the coming short rains season, and we are producing biochar to account

for that possibility. Analysis of the causes of any increased demand will of course be complicated, because the randomized treatments which we'll leverage to obtain causal estimates will no longer be as proximate in time. However, given the large number of demonstration plots, we expect that any signal caused by these new plots will be extractable from our dataset.

Most tangibly, we plan a major ramp-up of project activities in July, when we'll begin preparation for the endline survey. This will take place after the long rains harvest, and be followed up by a final round of biochar sales. After complete, field activities will close, and we'll begin final data analysis, complete final reports, etc.

Scaling Biochar: Demonstration Plot Results, EMMR, Cost/Benefit, and Gender Analysis

Andrew Crane-Droesch

31 January 2014

1 Overview

As of this writing, baseline and midline data collection are complete, and our project has shifted to implementation. Biochar demonstration plots were established on small portions of the fields of 75 farmers, and all but one of these has since been harvested and measured. Randomization of sales offers began along with biochar sales in early January, and are ongoing. Sales will continue through to the onset of the long rains – normally in early March – when farmers normally plant. After planting, the project will shift focus to the analysis of data on biochar adoption as a function of randomized demonstration plots, prices, and free trial offers. At harvest – expected in August – we will collect data to enable us to ascertain biochar's impact on yields, complimentary input expenditure and efficacy, and farm-level profitability.

This document serves to address the Jan 31 2014 project milestone, which includes a report on demonstration plot outcomes, an environmental management and mitigation report (EMMR), a mid-term cost/benefit analysis of our project with respect to alternative solutions, and an analysis of gendered impacts of our project. The sections that follow are organized along those themes. In summary, the demonstration plots showed generally strong yet variable results, with benefits correlating with previous yields and with fertilizer application rates. The EMMR is quite similar to the previous one, submitted in September 2013 – we include photos depicting crop development with and without biochar. We use demonstration plot results as a starting point to analyze likely costs and benefits of biochar as compared with other strategies for carbon sequestration and agricultural intensification, though we emphasize that robust results on impact won't be forthcoming until the endline survey, when we will measure the impacts of biochar on the fields of farmers who themselves have adopted. Finally, we present a prospective analysis of likely impacts disaggregated by gender, again with the caveat that these results will be in anticipation of more robust results that will be forthcoming first after all prospective adopters have adopted, and impacts on their fields have been measured.

2 Demonstration plot results

The 76 demonstration plots (one of which was eaten by a cow, leaving 75) consisted of a 1/8 acre parcel of land, to which biochar was applied to half. These halves were divided again into one parcel with either maize or another cereal crop, and another with a crop of the farmer's choice. (Some farmers ignored these instructions and planted only maize, or only another crop.) For each crop on each farmer's plot, we thus have an observation of yields with biochar compared to yields without. Those are presented in figure 1. Results were generally positive, though variable. Maize performed best in response to biochar, though there are more observations for this crop than for others represented. These data are presented spatially in

figure 2. There is little apparent spatial pattern to the distribution of demonstration plot results, while the randomization achieved semi-clustered heterogeneity in demonstration plot placement.

Farmers with demonstration plots were instructed to manage plots with biochar and without biochar identically, but otherwise input and management decisions were left to them. We explore differential response to biochar based on inputs and past yields and fertilizer use via regression (figure 3), in which the response ratio (the natural logarithm of the ratio of biochar yields to control yields) is set equal to a function of these variables. Positive response to biochar is associated with higher levels of CAN (calcium ammonium nitrate) and DAP (di-ammonium phosphate) fertilizer, and associated with lower levels of urea. This suggests, as we expected, that biochar may improve response to inorganic fertilizers. Positive response is only weakly (and not significantly) correlated with previous yields or fertilizer use. To the extent that these variables serve as proxies for soil quality and/or poverty, we are somewhat surprised to find little association.

For the most part, farmers report being satisfied with the results of the demonstration plots, and we anticipate higher takeup of biochar for sale among these farmers, and among those of their neighbors and social contacts who observed the results that we document here.

3 EMMR

Pursuant to the requirements of this project's EMMR mitigation plan, this section presents the following:

- Narrative report on biochar soil amendment effect on crops
- Photographs depicting crop development
- Description of our project's adherence to all Kenyan laws and regulations

3.1 Narrative Report

As of this writing, 76 biochar demonstration plots have been installed on the fields of randomly selected farmers in our project areas, and all but 1 has been harvested. The purpose of these demonstration plots was to inform both the plot hosts, as well as their neighbors, friends, and other social contacts, about the potential gains in crop yields resulting from biochar use. We are now beginning to make biochar production services available for sale; we expect to find that those farmers who have more social contacts with biochar demonstration plots will be more likely to invest in the service.

The demonstration plots were installed ahead of planting for the short rains season. Most farmers planted between the end of July and the end of August, 2013. Yields from demonstration plots were analyzed in the previous section.

3.2 Photographs depicting crop development

Implementation of demonstration plots (which consisted of producing biochar on portions of farmers fields and applying it to their soil in planting rows) was completed at the end of August. Once complete, our implementation team commenced monitoring visits to catalog crop development on the demonstration plots, and eventually to harvest them. The pictures below (figures 4,5 & 6) provide contrasts between the treatment (biochar) and control (no biochar) portions of the demonstration plots from 3 representative plots.

3.3 Adherence to Kenyan Law

Charcoal production is regulated in Kenya. Biochar, while similar to charcoal, is not charcoal: Kenyan law defines charcoal as "wood fuel product derived from carbonization of wood or other plant materials." Due to its friable and powdery structure, biochar cannot be used as a fuel, and thus is not under the jurisdiction of charcoal-related statutes.

A guide to the relevant Kenyan statutes can be found at `www.pisces.or.ke/sites/default/files/The%20Kenya%20Charcoal%20Policy%20Handbook.pdf`, and `http://www.theredddesk.org/sites/default/files/forest_charcoal_rules_2009.pdf`. In general, charcoal-related statutes are promulgated from within the forestry sector, rather than the agricultural sector (within which our project is operating).

4 Mid-term cost/benefit analysis

It is well-established in the agronomic literature that biochar can improve crop yields, particularly in the sorts of soils that characterize our Western Kenyan context. Thus, the results from our demonstration plots are unsurprising and indeed, relatively uninteresting. What is not well-established are dynamics of biochar adoption by smallholder farmers, nor the effect of biochar adoption on farmer welfare, which will be mediated both by biochar's agronomy and farmer behavior. Given that we don't yet have data on farmer behavior with regard to biochar adoption (we are collecting it now) or the consequences of this behavior (we will collect those data in August), we cannot give a definitive answer to the question: "is biochar 'worth it"' in economic terms.

We can however give a preliminary answer. Our general approach is to first estimate biochar's agronomic benefit (as mediated by complimentary fertilizers), then estimate baseline response to fertilizer absent biochar, then simulate the effects of biochar adoption at a variety of biochar prices. These in turn lead to a range of expected profitabilities depending on farmer characteristics, giving us a distribution of likely impacts at a variety of biochar prices, ranging from prices at which sales of biochar are profitable, to low prices which would require subsidies.

We begin by estimating a statistical model representing the results of the maize demonstration plots as a function of the complimentary inputs added and previous maize yields and fertilizer additions:

$$RR = \alpha + f(DAP) + f(CAN) + f(Urea) + f(PrevYield) + f(PrevFert) + \varepsilon \tag{1}$$

where RR is the response ratio, defined as the logarithm of the biochar plot yield divided by the control plot yield. Results are given in figure 3, and provide estimates of likely response – in terms of change from baseline yields – to biochar conditional on fertilizer application. Response to biochar is increasing in CAN and DAP use, and slightly negative, though not significantly so, in previous yields, fertilizer use, and urea use. We then estimate a fixed-effects regression model representing maize yields as a function of farmer-level fixed effects and fertilizer expenditure, using data collected in the midline survey, on agricultural inputs and outputs over the past three years:

$$yield_{it} = \alpha_i + f(FertExpend_{it}) + \varepsilon_{it} \tag{2}$$

Results are given in figure 7 – on average, yields are increasing in fertilizer, though with declining marginal yields at higher application rates.

To estimate the effect of biochar on agricultural profits at a given price, we first define $ProfDif \equiv BiocharProfit - BaselineProfit$. Baseline profit is defined simply as average yields per-farmer, multiplied by the market

price of maize, less the cost of their average fertilizer expenditure, over the three years for which we have data. Biochar profit is defined as:

$$BiocharProfit_{ip} = \widehat{yield}_{ip} * e^{\widehat{RR}_{ip}} - FertExpend_{ip} - BCPrice_p \tag{3}$$

where i indexes farmers and p indexes biochar prices. The highest biochar prices that we consider is KSh5000/acre, or $145/ha, which is approximately double our project's break-even point for sold biochar (and which also constitutes the maximum price which a farmer in our sample may randomly draw). The term $\widehat{yield}_{ip}$ is calculated as expected yields for farmer i at their normal fertilizer expenditure, minus the cost of biochar. The term $\widehat{RR}_{ip}$ gives the expected response ratio by which biochar modifies expected yields, which varies with biochar price by changing the amounts of fertilizer (which mediate biochar's efficacy) applied with biochar, such that average agricultural expenditure remains unchanged. Farmer who normally spend less on fertilizer than $BCPrice_p$ are modeled as not adopting biochar, as are those for whom our model would suggest that it would be unprofitable. Those results, for a range of biochar prices, are given in figure 8.

For most farmers, biochar at the highest price that we consider would not be profitable – biochar becomes profitable for the median farmer at approximately $40/ha (at an application rate of approximately 500kg/ha). This is almost certainly an underestimate of biochar's profitability however – given that biochar's benefit in soil has been shown to be durable over a number of years, and given that figure 8 represents potential gains for only one season.

The region of the figure to the right of the vertical line represents prices which would require subsidies, and the dotted green line indicates the ratio of the subsidy expenditure to the benefit derived by farmers. While small subsidies are very cost effective in terms of return on investment, large subsidies – all the way to giving biochar away completely for free – generate more gain than they cost to provide.

We compare the benefit/cost of biochar to the benefit/cost of subsidizing inorganic fertilizer. We approach the analysis similarly – for each biochar pricepoint, we take the associated subsidy (defined as the sum of the subsidy payments for those who avail themselves of them), and distribute that money to all farmers in our sample in the form of extra fertilizer (which all adopt, given that the benefits we model are strictly increasing). Benefits are more homogenous in this scenario, given in figure 9.

Comparing the two (by subtracting the distributions from one another), we find that subsidized fertilizer is better for more farmers in the short term than subsidized biochar, though a substantial portion of our sample would be better off with subsidized biochar (figure 10). Short-term benefits are misleading however. If, for example, biochar were to be subsidized for one season, and many farmers adopted biochar, those farmers would get direct benefits during the next season from the biochar which they had added in the past, at zero present cost. Furthermore, their inputs of costly fertilizer would likely be more effective than they would otherwise be. However, we lack Kenya-specific data on multi-year response to biochar, and are thus unable to quantify these prospective benefits at this juncture. Absent subsidies, biochar remains beneficial for a substantial fraction of our sample, even in the short term.

Up to now we have been concerned only with biochar's agronomic benefit. However, biochar also provides a public good in the form of carbon sequestration. At the application rates that we are using – approximately 500kg/ha – we assume conservatively that half of this mass is carbon, and that half of this carbon is "stable[1]" – we are applying 125kg of stable carbon per hectare. Figure 11 gives amounts of carbon sequestered per dollar social cost (which is negative, indicating social benefit), and per farmer. Total amounts of carbon are modest on a per-farmer basis, but benefits per ton of carbon are quite large.

[1]Biochar turnover time is long, yet poorly constrained. Recent studies give estimates anywhere between hundred to tens of thousands of years.

Total mitigation benefits are modest – scaled to reach 25% of Kenya's 58 million agricultural hectares, our assumptions suggest that biochar would sequester 600,000 tons of carbon per year – equivalent to the annual emissions of approximately 46,000 average American households, or 1.3% of Kenya's greenhouse gas emissions. However modest these mitigation benefits may be, their negative cost improves their value relative to several costlier solutions. Furthermore, these benefits represent carbon removed from the atmosphere, rather than avoided emissions. As such, they are more effective, given that only approximately 45% of emitted carbon remains in the atmosphere (the "airborne fraction"), and, if humanity is ever successful in attaining carbon neutrality (with respect to the airborne fraction), these gains would represent carbon removed from the atmosphere – reversing the buildup of carbon in the atmosphere, however slowly.

5 Gender analysis

It is well-recognized that many development interventions have differential impacts on men and women. In many parts of sub-Saharan Africa, woman are responsible for a large portion of farm work, but yet have little influence over agricultural decisions. As our project moves through implementation, we plan to analyze heterogeneity in uptake rates by gender of the head of the household.

This data is currently being collected, as biochar is beginning to be offered for sale for the upcoming long rains season. Much in the same vein as the preceding sections, we offer a prospective analysis of gendered impacts – taking the estimated prospective benefits of biochar adoption at a variety of prices, and disaggregate them by the gender of the head of the household. Those estimates are presented in figure 12. Under the assumptions guiding this prospective analysis, there is little difference in prospective benefit between the 851 male-headed and 100 female-headed households[2] – the distributions overlap substantially. Furthermore, agricultural summary statistics – when disaggregated by the gender of the head of the household – also show little difference by gender (figure 13).

Note that prospective benefit calculations assume that farmers will adopt biochar if its apparent costs are exceeded by its benefits – a dubious assumption in the real world. We look forward to collecting data which will enable us to measure gender difference in adoption propensity.

6 Figures and tables

[2]Female-headedness was operationally-defined as households where the female respondent – all respondents were those responsible for agricultural decisions in the family – was either unmarried or a widow.

Figure 1: Results on biochar demonstration plots. The diagonal line demarcates negative from positive contrasts. Yields per plot converted to ton/ha equivalent.

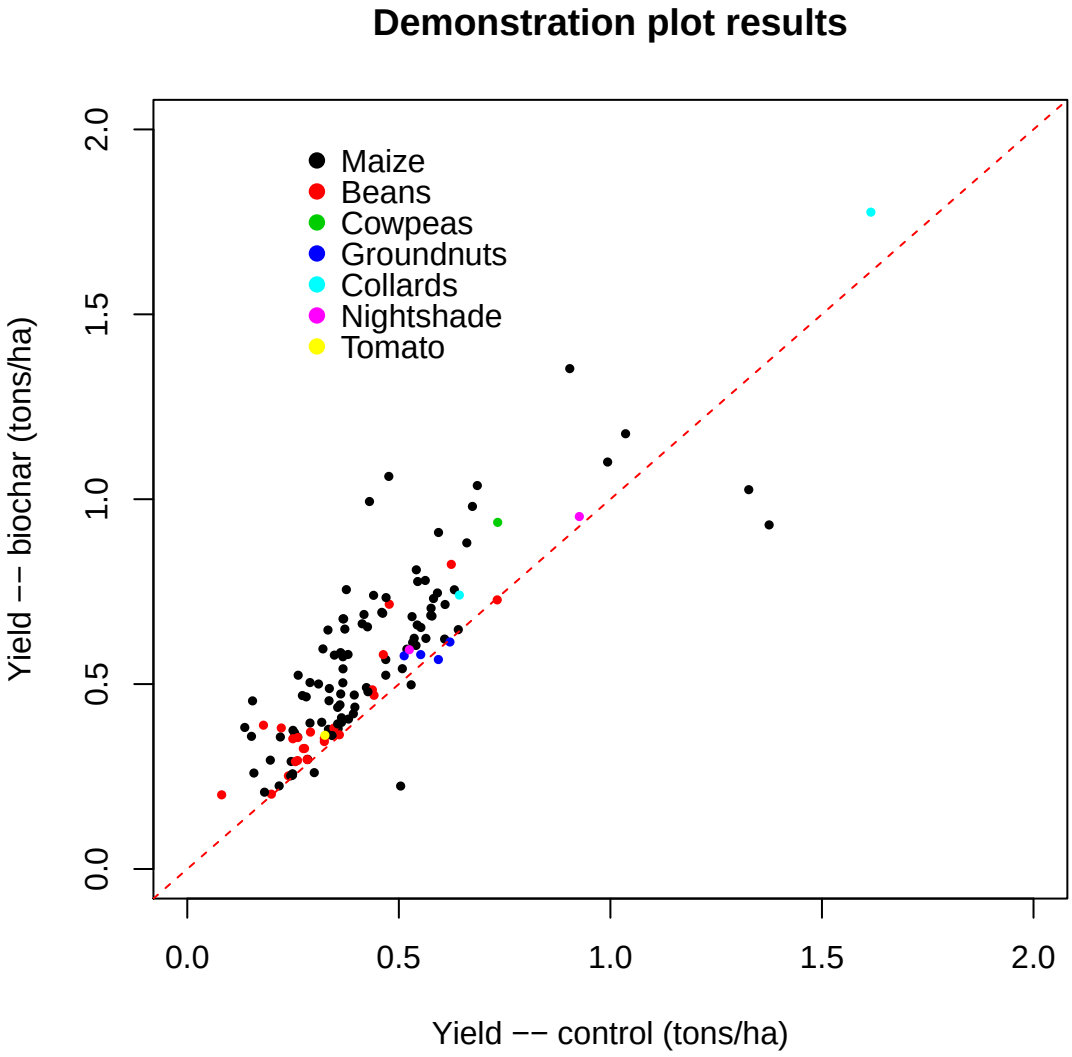


Figure 2: Results on biochar demonstration plots, presented spatially. Small dots indicate respondents, large semi-transparent dots indicate demonstration plots. Relative transparency in green (red) dots gives the magnitude of positive (negative) results in relative terms. Results subset to maize.

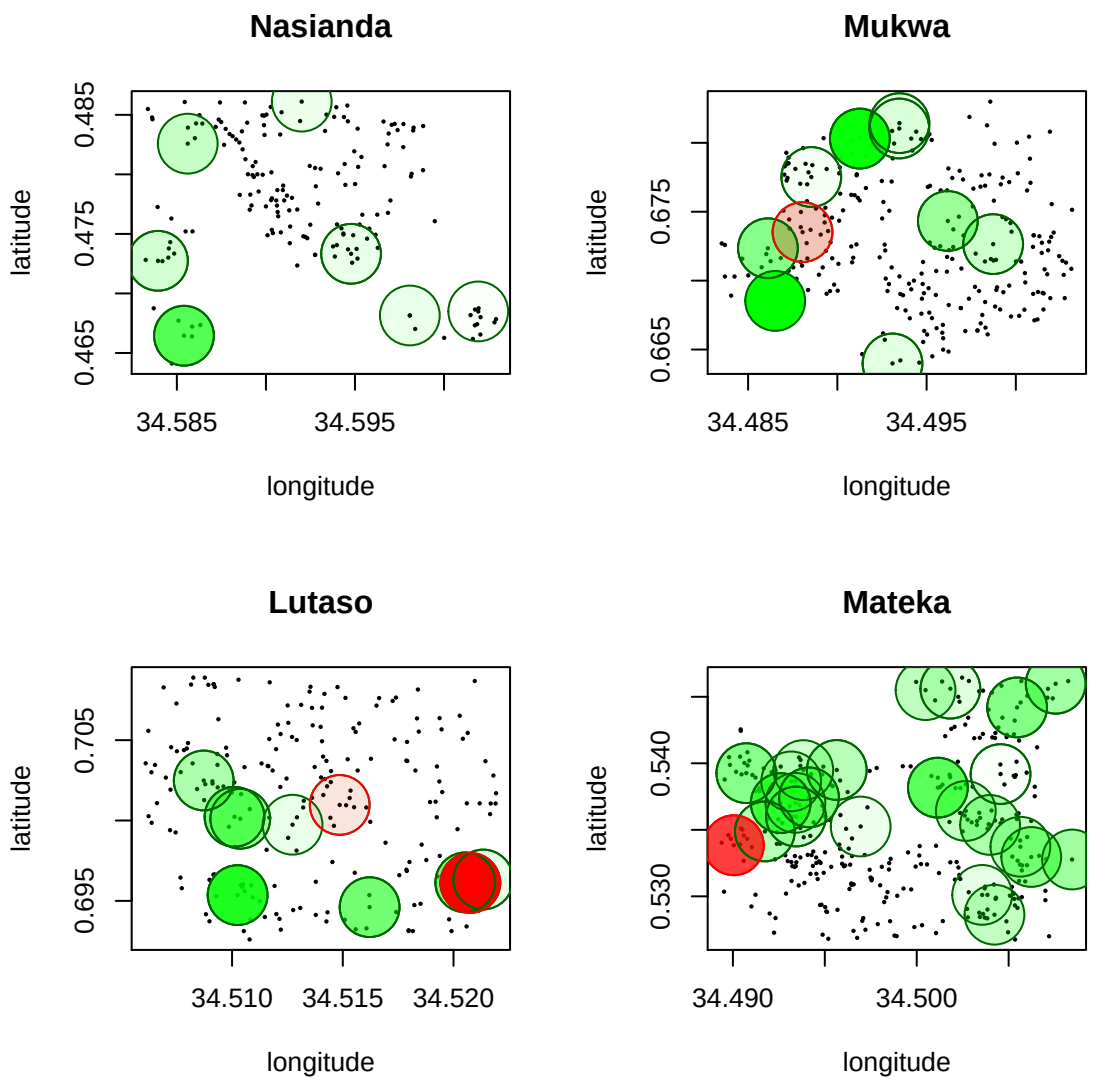


Figure 3: Regression results modeling response ratio (ln(biochar yield/control yield)) on maize demonstration plots as a function of DAP fertilizer, CAN fertilizer, Urea fertilizer, previous average crop yields, and previous average fertilizer use.

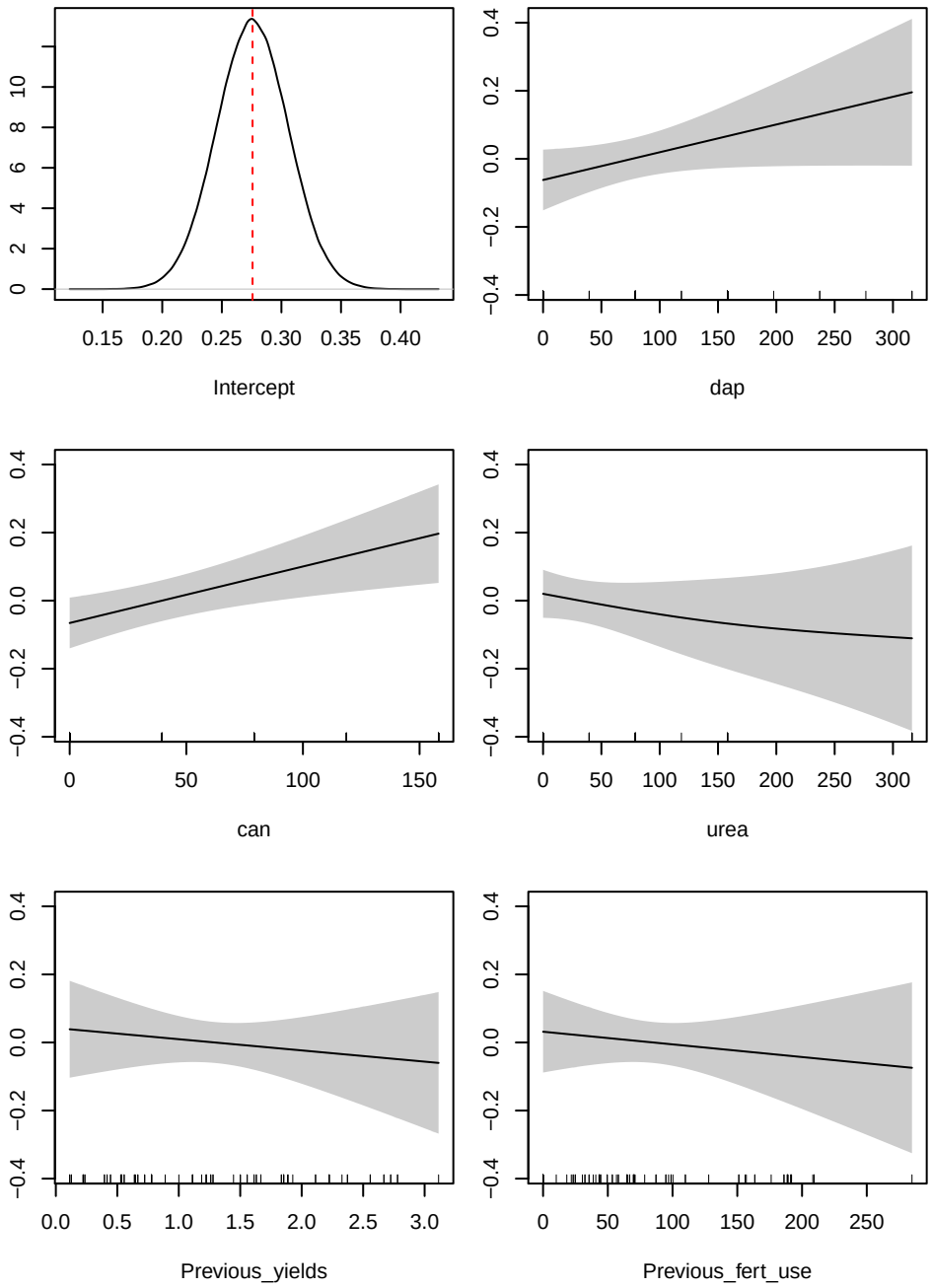


Figure 4: Example of a demonstration plot; with biochar above, without below. Note in this picture enhanced vegetative growth in the biochar plot.

Figure 5: Example of a demonstration plot; without biochar above, with below. Note in this picture purple streaks on leaf – an indication of poor phosphorous uptake, which can inhibit grain filling. Note the full cob on the plot with biochar.

Figure 6: Example of a demonstration plot; without biochar above, with below. Note thicker vegetation and thicker maize cobs on the demonstration plot, as compared to the control.

Figure 7: Estimates from equation 2. The left figure gives estimates of farmer-level fixed effects, and right figure gives estimates of the effect of fertilizer on maize yields. Estimates of yields for a given farmer sum the estimate farmer effect and the effect of fertilizer at a given level.

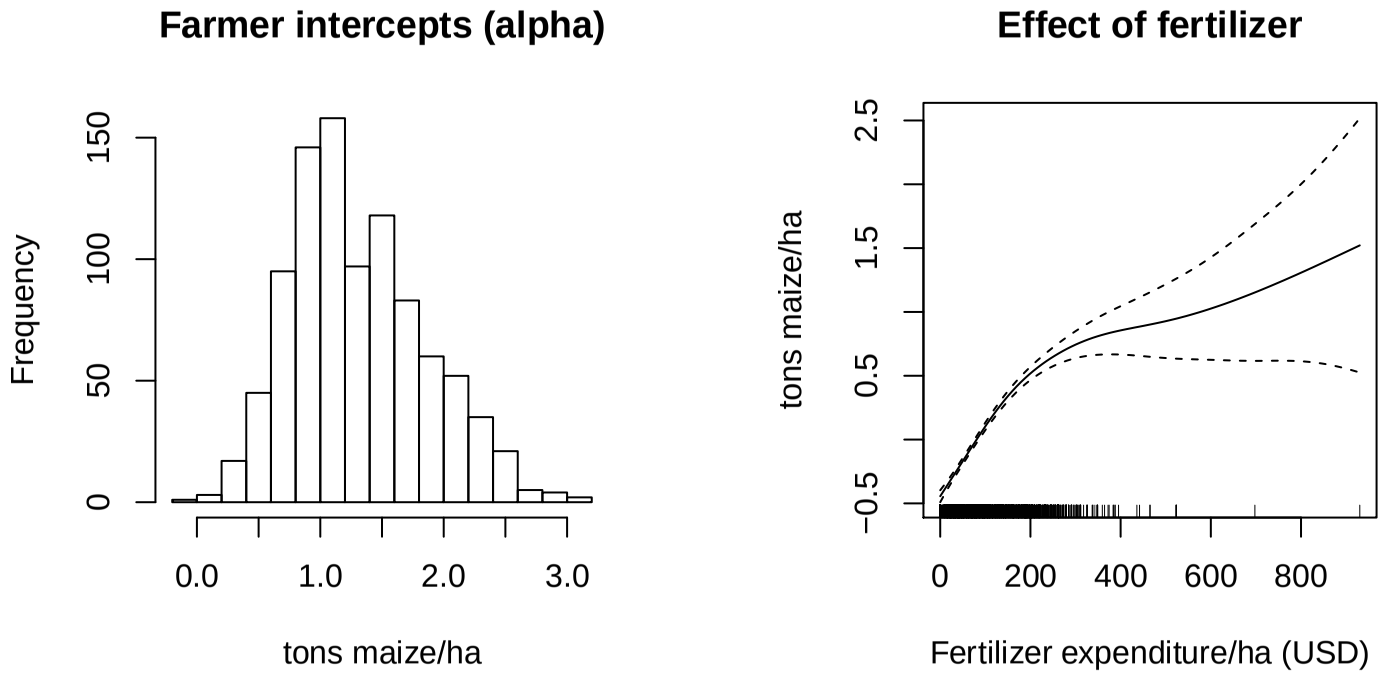


Figure 8: Costs and benefits of biochar at a variety of subsidies, assuming a base price of Ksh5000/acre, or ∼$145/ha. Semi-transparent blue points indicate per-farmer projected differences between the no-biochar baseline, and an alternative scenario wherein the farmer uses biochar at a price indicated on the x-axis. All costs to the right of the vertical line indicate prices at which biochar should be profit-making, not requiring subsidies.

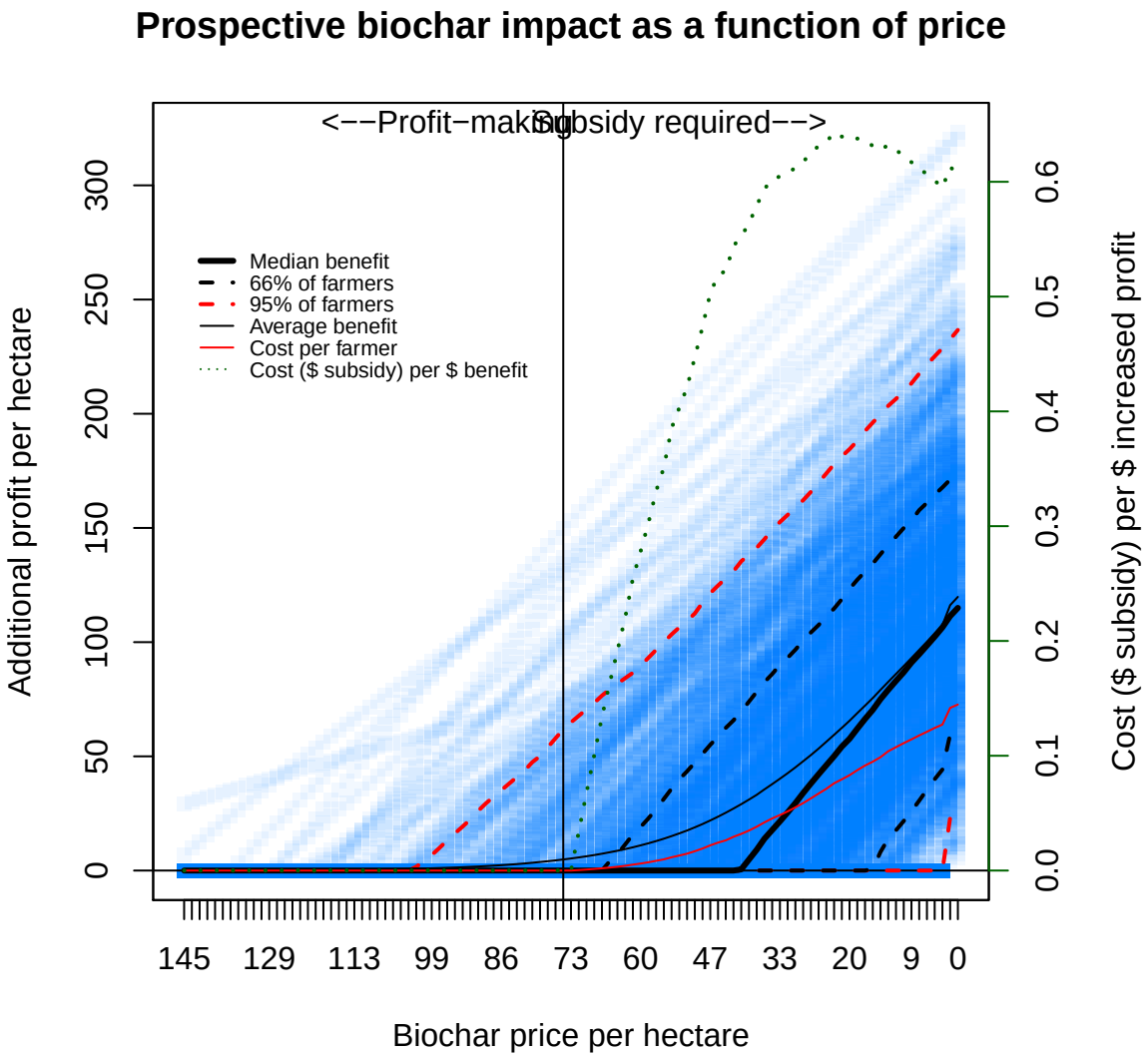


Figure 9: Benefits and costs under a scenario under which fertilizer is subsidized using money equivalent to the subsidies spent on biochar in the biochar scenario. Semi-transparent blue points indicate per-farmer projected differences between the baseline scenario and an alternative scenario wherein the farmer uses extra subsidized fertilizer (defined by the equivalent of the biochar subsidy). Flat response on the left side of the curve indicates areas where biochar sibsidies are zero due to biochar's profitability in those regions.

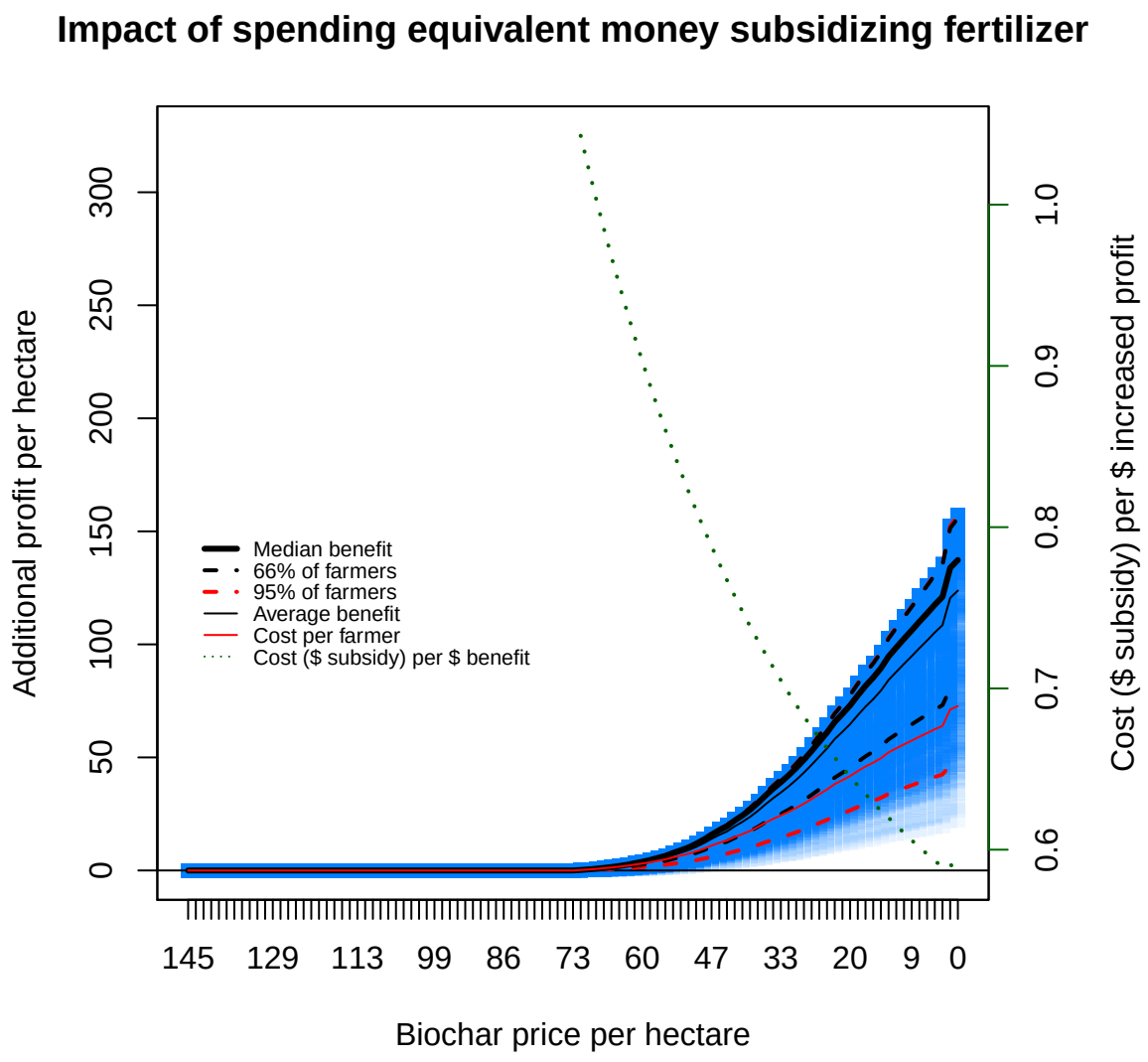


Figure 10: Comparison of benefits of subsidized biochar versus subsidized fertilizer. The are to the left of the vertical line represents unsubsidized, profit-making biochar. The y-axis gives the difference in additional profit between the two scenarios. Fertilizer subsidies are set equivalent to biochar subsidies, and are therefore zero to the left of the vertical line.

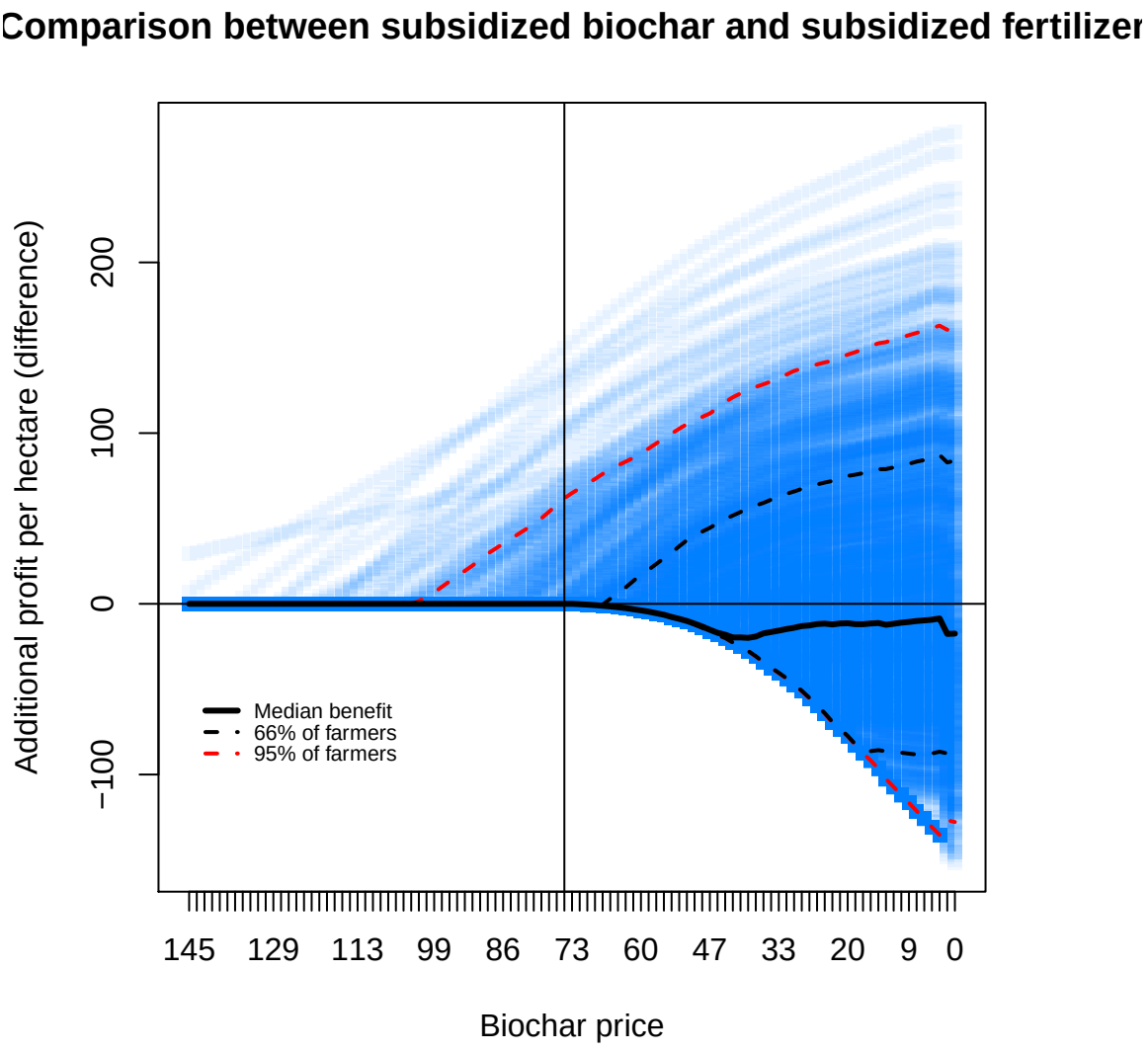


Figure 11: Social and program costs of carbon sequestration via biochar. Left figures give costs per ton of carbon, right figures give total carbon per farmer per year. Upper figures give social costs (defined as program costs minus benefits, lower figures give program costs only).

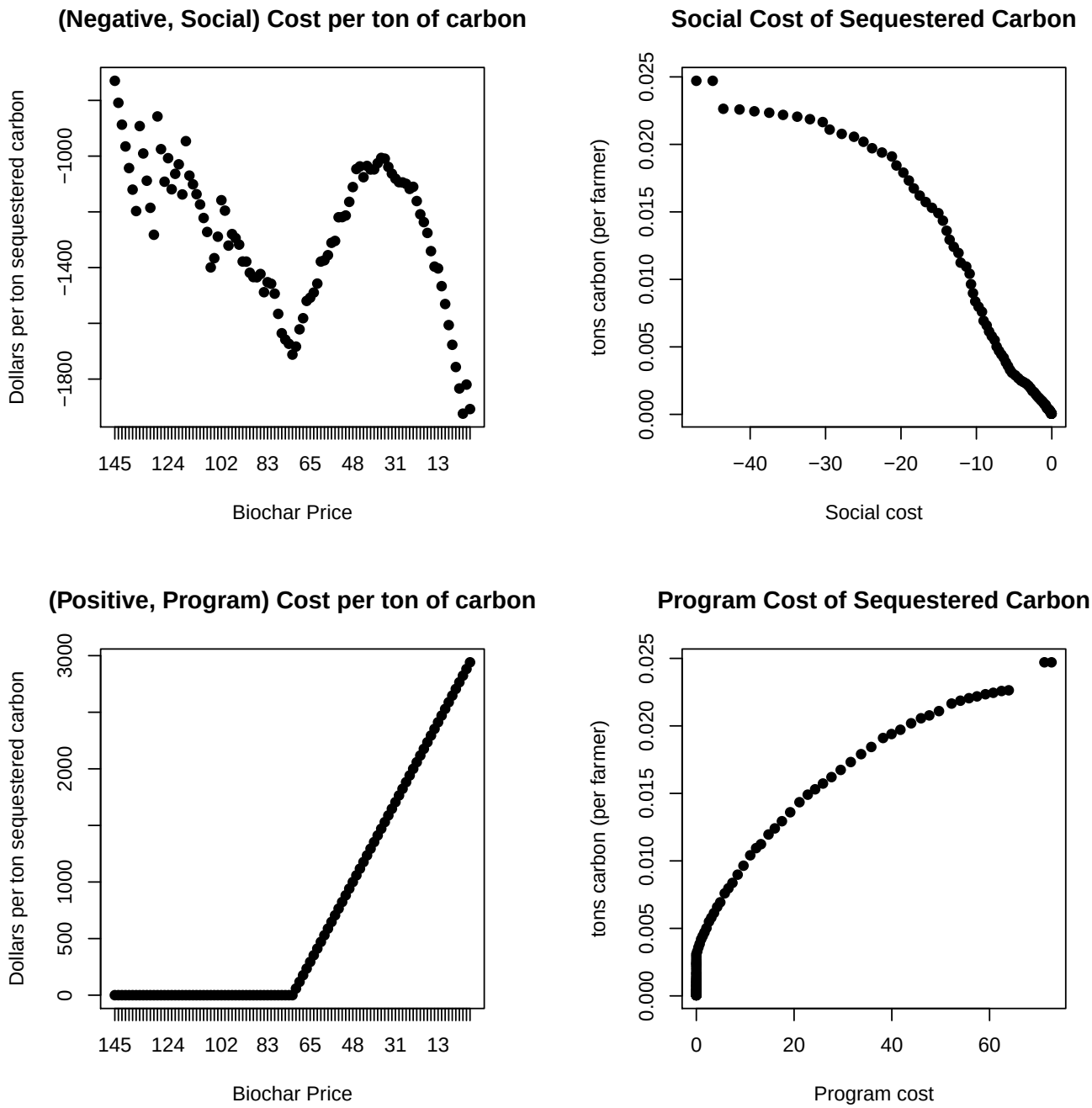
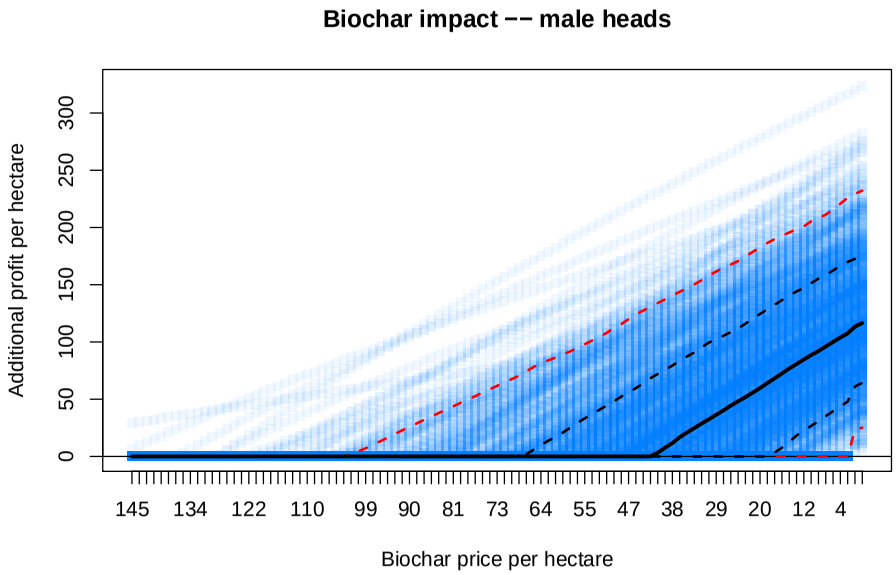


Figure 12: Prospective biochar benefits disaggregated by gender of head of household.



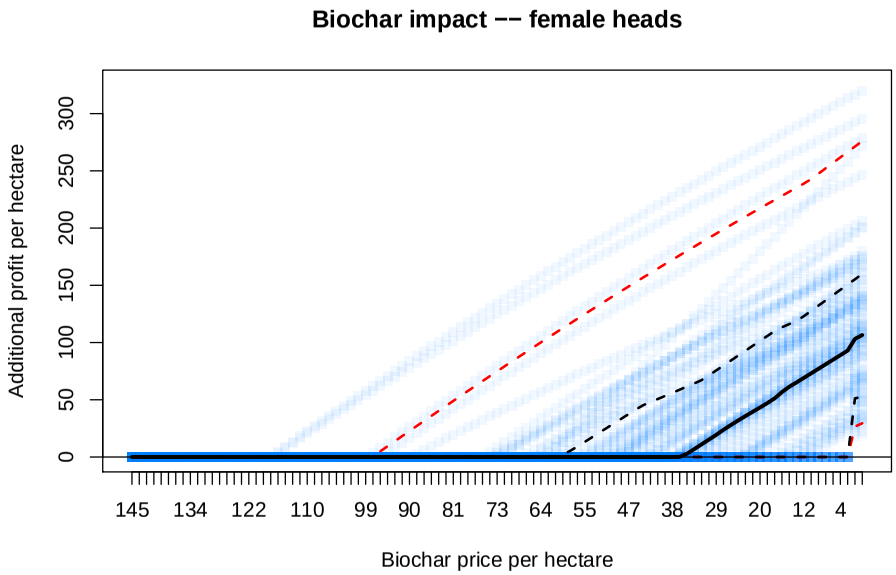
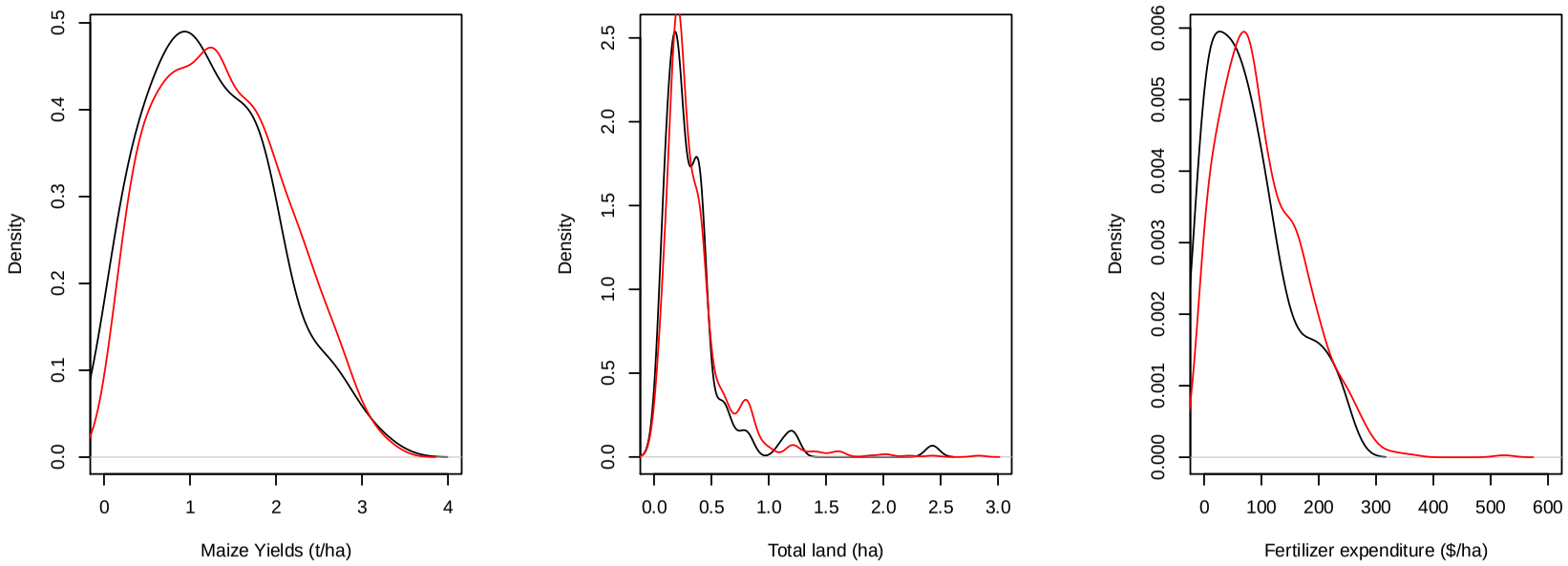


Figure 13: Agricultural summary statistics – density plots by gender (female-headed households in black, male-headed households in red).



Scaling Biochar: Milestone 11 Report

Andrew Crane-Droesch

November 2014

1 Overview

With the majority of the project's fieldwork finished, this report provides a summary of results on biochar adoption and impact on crop yields across two seasons. Further analysis and discussion will be provided in the final report in January 2015.

2 Biochar adoption in the long rains 2014

As described in previous reports, we chose 75 of our respondents at random to receive a biochar demonstration plot during the runup to the 2013 short rains season, in July-September. Because those demonstration plots were randomly allocated, the share of a given farmer's social network with a biochar demonstration plot was also random. Those demonstration plot results are summarized in figure 1.

After the demonstration plots were harvested, we randomly allocated prices and free trial offers to farmers in our sample. These are summarized in figure 2. Prices represented the price that a farmer faced in order to have biochar applied to a 1/4-acre plot of their farm – our workers would come and either apply pre-made biochar to their farm, or produce it there from available materials nearby. If a farmer received a free trial offer, they'd be able to get 1/4 acre applied with biochar on credit, with no obligation to repay until harvest. At harvest, they could refuse to repay – with no consequence – if they believed that the result was not worth the price. If they made that choice, they were told that they would not be able to purchase biochar from us in the future.

We began selling biochar in February 2014 and continued into April – the planting season for the main (long) rainy season. In total, 160 farmers adopted biochar. Of these however, only 10 paid cash – 150 of those who adopted biochar got it on a free-trial basis 3. Having a demonstration plot made farmers more likely to adopt as well, though the effect was not as strong as the effect of being offered a free trial – presumably these farmers had seen the results of biochar on their own farms, increasing their demand (figure 4). Similarly, those who faced lower prices were substantially more

likely to adopt (figure 5). However, those who adopted had no greater proportion of demonstration plot holders with biochar in their network than those who didn't – it appears that social learning had no effect (figure 6). Combining each of these treatments into a binomial statistical model yields similar conclusions (figure 7): the major predictor of adoption was being offered the free trial, with minor roles for price, and a barely detectable positive effect of the social network, but only for those who were offered the lowest price.

3 Yield results on the fields of adopters

During the growing season between March and July 2014, we collected plot-level data on the fields of those who had gotten biochar for that season. This included amounts of fertilizers used, land sizes, and whether the biochar used was placed on relatively more or less fertile portions of fields. On average, biochar plots were 46% the size of non-biochar plots, received 25% less fertilizer, and were usually less-fertile (49%) or of similar fertility (50%). Taking these variables into account, we can estimate what yields farmers would have received had they treated the two plots equally. These results are shown – both raw and adjusted – in figure 8. On average, biochar increased maize yields by .77 tons per hectare, or by .91 tons/hectare if non-equal treatment of the plots is taken into account. This represents a 60% (raw) or 76% (adjusted) increase in yields. For a hypothetical farmer who purchased biochar at KSh1250 per 1/4 acre, this represents more than a doubling of that investment.

Paradoxically however, these results are not reflected in farmer's reported perceptions of yields on biochar plots (figure 9). Furthermore, while measurements of yields show large increases, estimates of increase derived from survey data – asking farmers about yields – show no effect of biochar adoption. While the cause of this discrepancy is still being explored, we speculate that farmers – being aware that the project was a research project – gave inaccurate data based on a perception that their answers might affect their probability of getting some better benefit relative to their peers.

4 Biochar adoption in August-September 2014

Because adoption in the previous season had been so low, and because those who adopted tended to do so only at the lowest prices, we re-randomized and lowered prices for the 2014 short rains planting season. This season, 25kg bags of biochar – sufficient for about 1/8 acre – were offered for a price between 50 and 400KSh ($.57 - $4.60), while those with free trials to repay were given a discount between 50 and 90% on the amount that they had to repay.

Only 13% of the farmers who had free trials repaid them, even with the discount. Controlling for the level of the discount offered, the only variable that was significant related to propensity to repay

was previous month income – only those with incomes much higher than average were significantly more likely to repay; there is no correlation between repayment and the measured result of the demonstration plot, or their reported impression of the result.

In total 96 people – about 10% of the sample – purchased biochar for the 2014 short rains. The average price at which they got biochar was 142KSh per bag (about $1.7), and the average purchaser bought 1.8 bags. The only significant predictor of buying biochar was biochar price – with those receiving the lowest price being 80% likely to adopt, and those receiving the highest price being 10% likely to adopt.

5 Conclusions

In sum, biochar had substantial impacts on crop yields, though farmers generally did not seize upon it as we expected that they would given that level of observed benefit. Subsidies are effective in stimulating demand, yet are expensive, and often unattractive to policymakers from a fiscal standpoint. However, we are not seeing effective ways around them – at least in the present context. More detailed analysis and discussion of all of the above will be provided in the final report, which will be provided in January 2015.

Figure 1: Yield results on demonstration plots, established during the short rains 2013. Diagonal lines represent percentage relative increases of the biochar plots over the control plots.

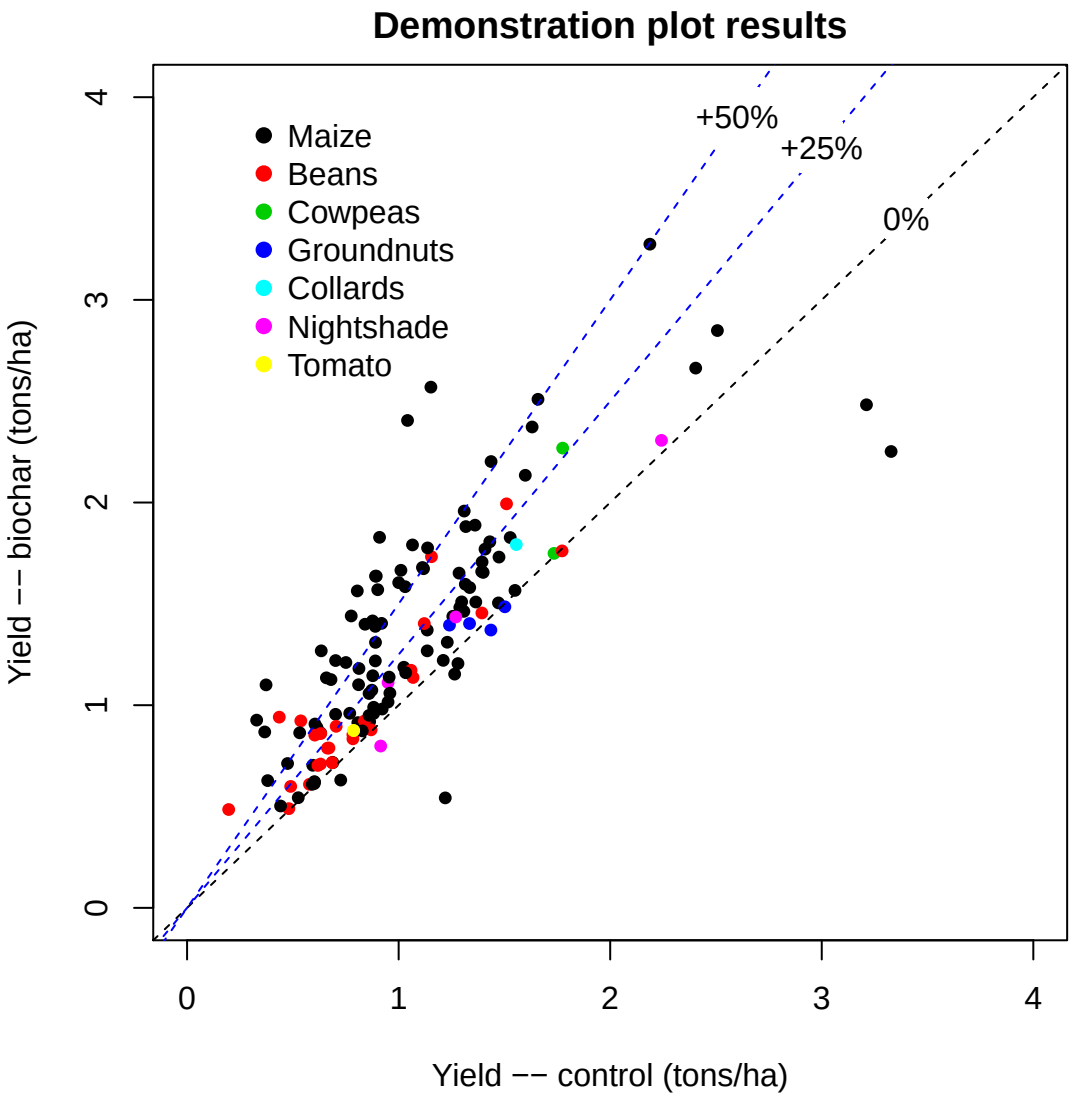


Figure 2: Allocation of prices and free trial offers among farmers in our sample.

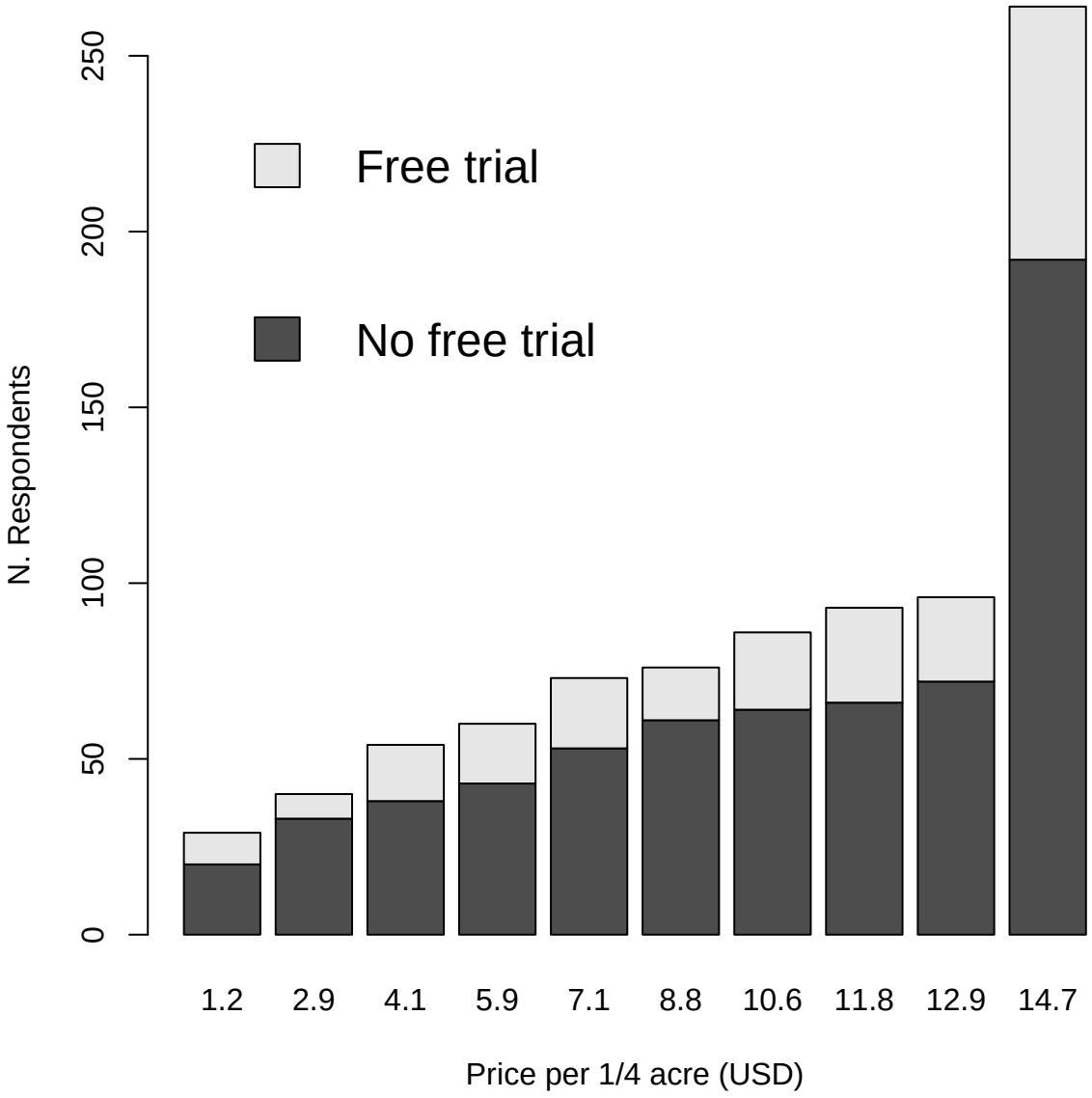


Figure 3: Proportions of farmers adoption biochar, by free trial offer status.

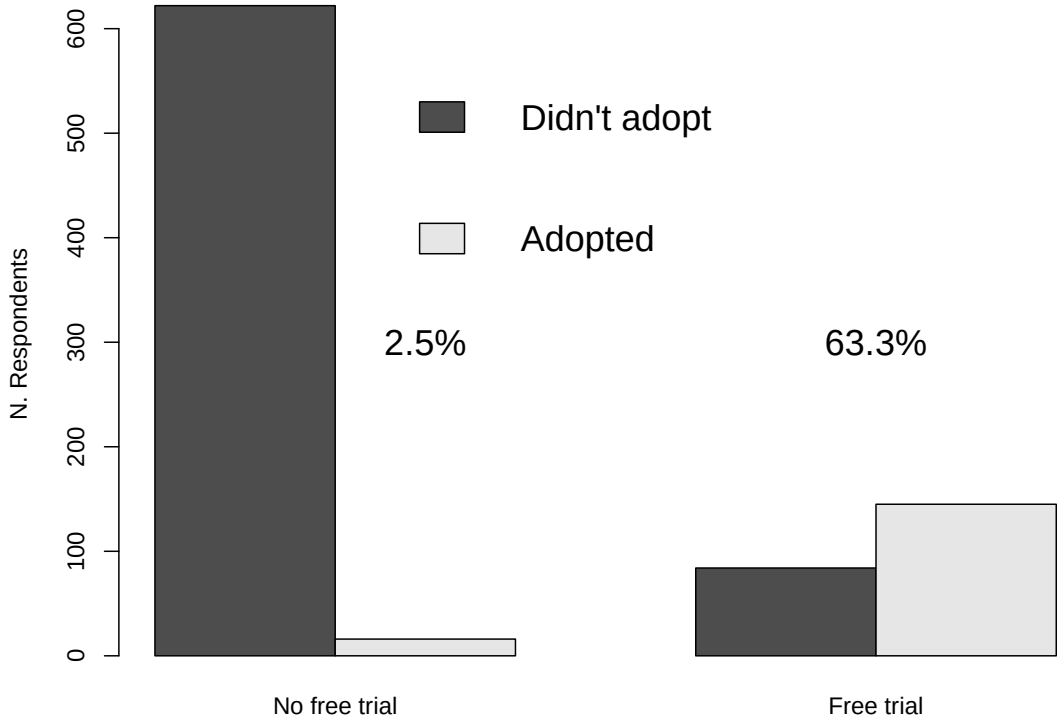


Figure 4: Proportions of farmers adoption biochar, by 2013 demonstration plot status.

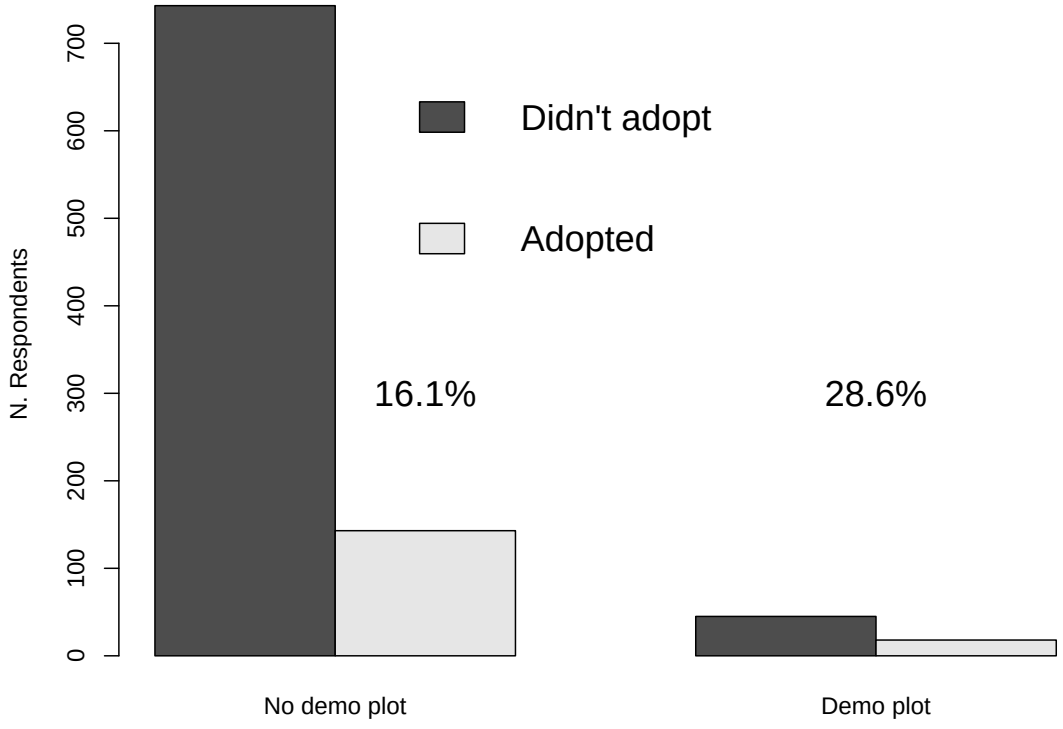


Figure 5: Proportions of farmers adoption biochar, price offered.

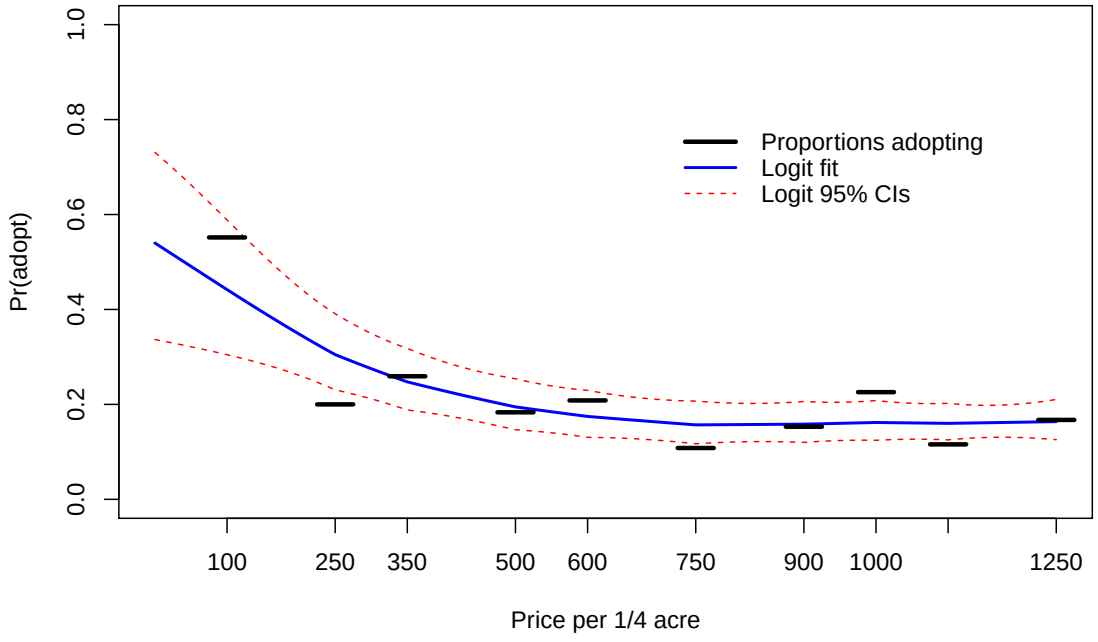


Figure 6: Share of links (left) and number of links (right) with demonstration plots, and proportions adopting biochar.

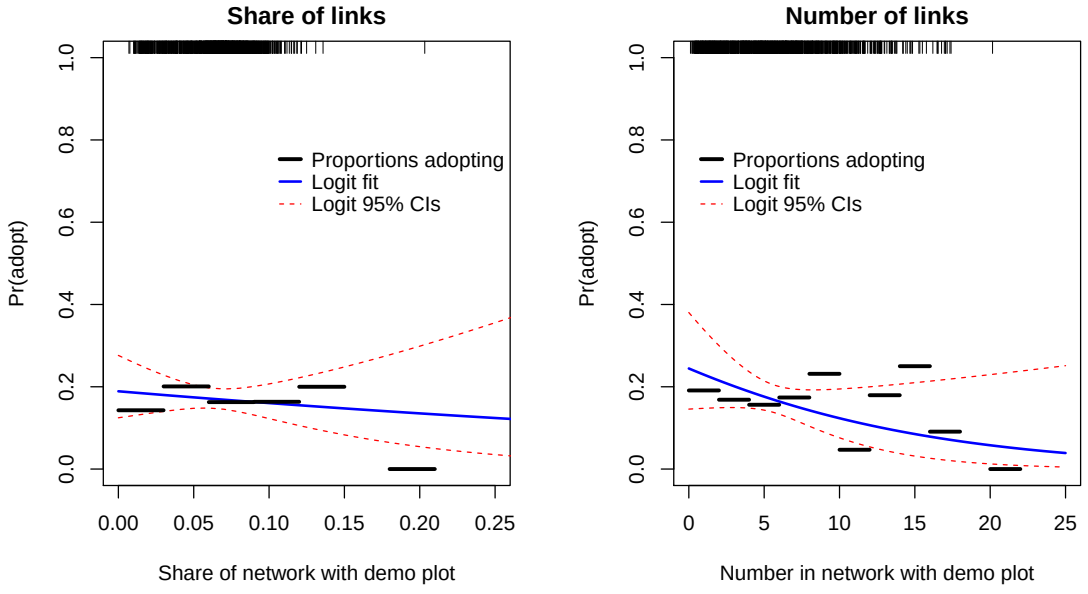


Figure 7: Results of the model $pr(adopt) = \Lambda\left[\alpha + \beta_1 FT + \beta_2 Demo + f(share, price) + f(price, FT) + \epsilon\right]$. Plots represent marginal effects of the plotted variables on the probability of adoption, at the mean values of non-plotted variables.

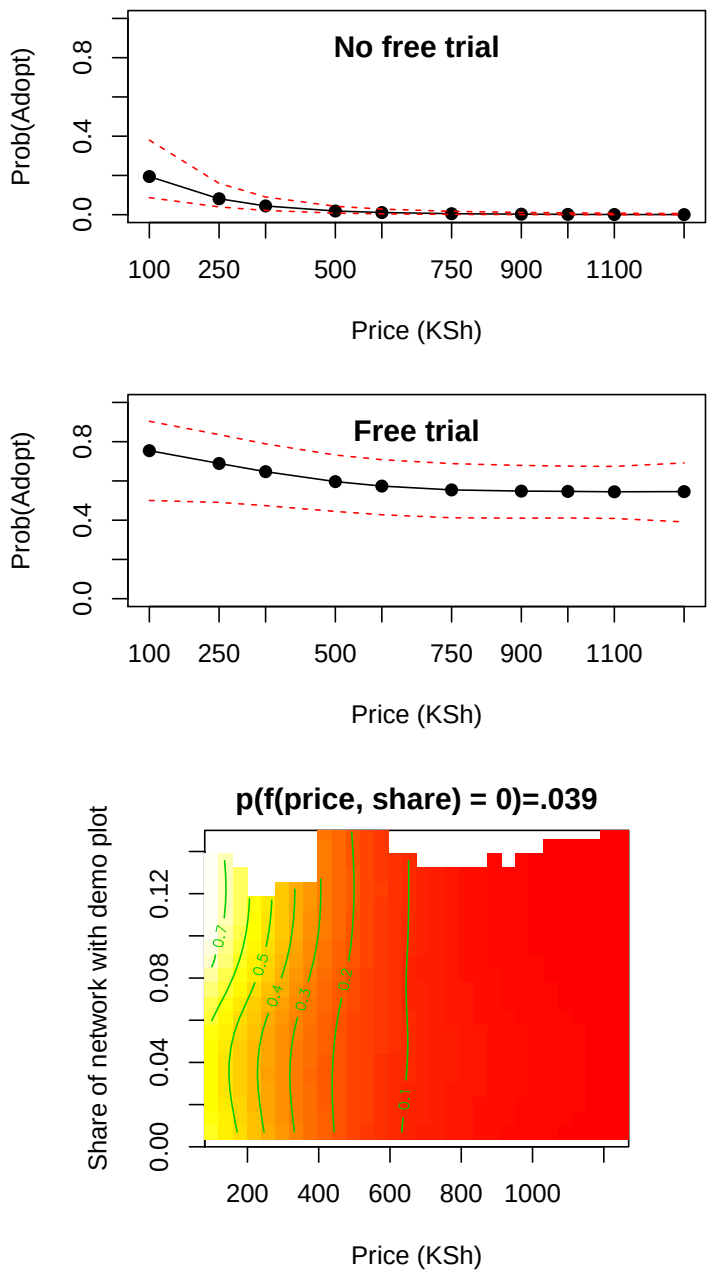


Figure 8: Measurements of yield on the fields of early adopters. Left plot shows raw data, with a nonlinear fit based on a gamma model. Right plot shows data adjusted based on our estimate of what yields would have been had farmers treated the two plots equally with respect to fertilizer use and land allocation.

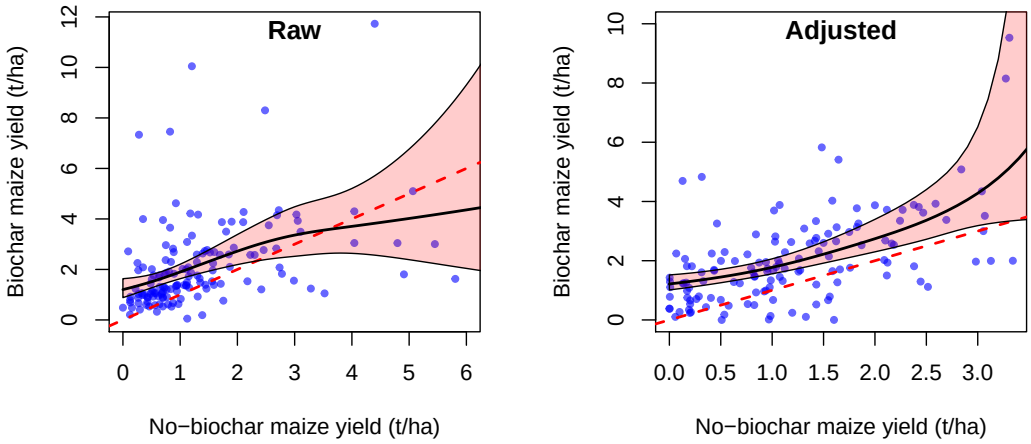
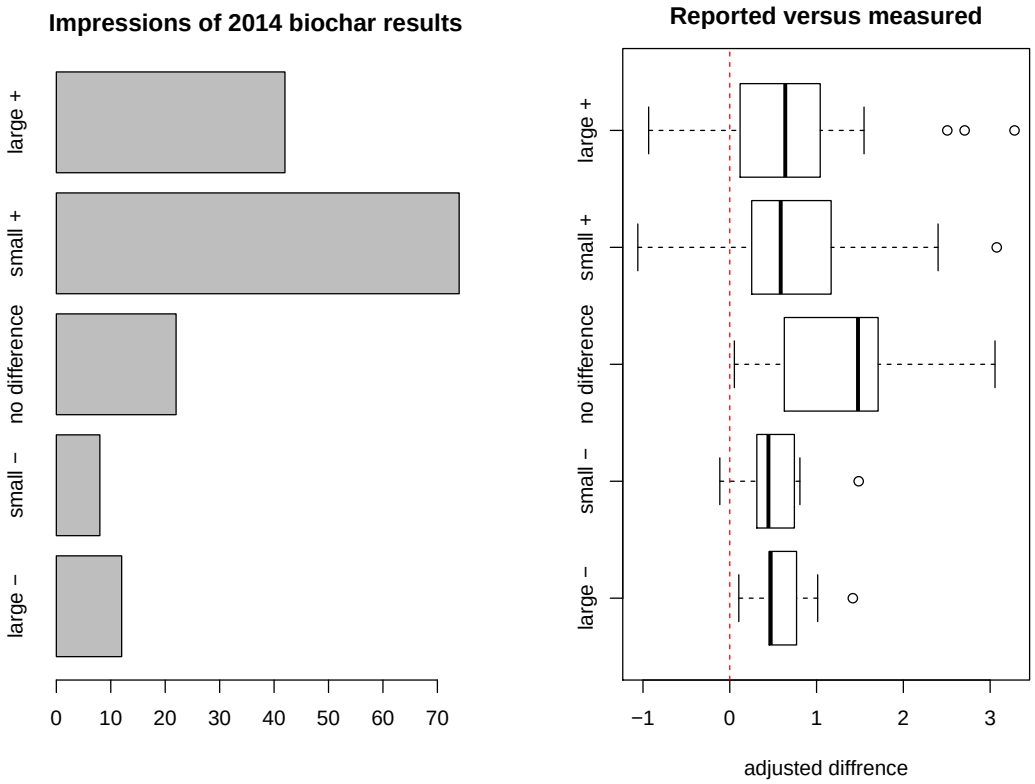


Figure 9: Impressions of the difference between the portion of adopting farmers farms with biochar, as compared to the portions of farms without biochar (left), verus the measured differences between the one and the other (right).



Subsidies, Social Learning, and Charcoal Dust: Impact and Adoption Dynamics of Biochar in Western Kenya

Preliminary/incomplete: please do not share or cite

Andrew Crane-Droesch

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First version: December 12, 2014
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Abstract

Dissemination of agricultural technologies remains a challenge in sub-Saharan Africa. I report the results of a randomized controlled trial in rural Western Kenya on adoption and impact of biochar, a novel input that can durably improve fertility in poor soils while sequestering carbon. To induce uptake, I randomly assigned prices, demonstration plots (aimed at stimulating learning), and deferred payment offers whereby farmers could choose to pay after harvest (aimed at reducing risk and liquidity constraints). Subsidies ranged from 0-87%, and full price is similar to that of recommended rates of inorganic fertilizer. In spite of yield increases of 37% and 50% in the first and second seasons, uptake was 2.6% and 10% respectively. Only 13% of (optional) deferred payment offers were paid following harvest, though these farmers were aware that this disqualified them from receiving more biochar. I find an inverted u-shaped relationship between biochar uptake and the share of the social network with biochar in the second season, and that increasing the share of a farmer's network from 5 to 10% increases their odds of adoption by a factor of 8.5 – an effect equivalent to a 53% subsidy. However, given very low uptake at no subsidy, the expected probability of biochar adoption only reaches 50% – at the optimally treated share of the social network – when biochar is offered at a 65% subsidy. While social learning can be a tool for technology dissemination, its effects here are conditional on baseline adoption propensity, which is conditional on subsidies. Given uptake well below the social optimum by the end of the project, heavy subsidies appear justified from a social cost/benefit standpoint. [1]

*https://www.dropbox.com/s/djeddvnect5f8hz/ACD_JMP.pdf?dl=0

[1] I gratefully acknowledge funding from USAID/Development Innovation Ventures, the US Borlaug Fellowship in

1 Introduction

Since independence, African agricultural productivity and input use has grown very little, while the population remains overwhelmingly rural and poor [1]. This stagnation is particularly stark in contrast to the massive gains experienced by most of the rest of the world during the same period. Driven by development of hybrid seed and inorganic fertilizer, the post-WWII "green revolution" is credited with much of the gain experienced elsewhere, and considerable attention has been paid to whether and how this experience might be replicated in sub-Saharan Africa [2–5].

Increasingly, institutional and academic discourses around agricultural development in the region have focused on "climate smart" agriculture – a term encompassing the integration of climate change mitigation and adaptation into development assistance in the sector [6]. Climate smart agriculture rests somewhat uneasily with the aim of agricultural development through increased use of inorganic fertilizer, as inorganic fertilizers can be relatively greenhouse gas-intensive in both production and use.

Fertilizer's profitability [7] as well as its agronomic efficacy [8, 9] can be quite variable in the region. However, this profitability is often mediated by soil carbon content, particularly in the geologically weathered soils common to much of sub-Saharan Africa [10, 11]. Thus, measures that increase soil carbon content can mitigate climate change via carbon sequestration, while potentially stimulating agricultural development via improving responsiveness to fertilizer.

The past several decades have seen substantial agroecological research around this prospect. Approaches have included agroforestry, conservation agriculture, composting/manuring, among several others [12–14]. Agronomic response is commonly strong, but benefits can take several years to materialize, and adoption rates are often low while disadoption rates among early adopters are high [15, 16]. Particularly in the context of growing opportunities to finance such projects under emerging international climate governance regimes [17, 18], evidence is needed on how to use these resources most efficiently to stimulate dissemination, yet relatively little literature focuses on this area [19].

Concomitantly, problems of technology adoption in African agriculture have received substantial attention in development economics – largely in isolation from work in climate-smart agriculture. Following the liberalization of agricultural input markets in the 1980s and 90s, much of this work has focused on means of stimulating adoption of improved agricultural technologies while avoiding the use of blanket subsidies, which were considered expensive, inefficient, and potentially regressive [20] in the way they were implemented. Given that the technologies subsidized were generally profitable in expectation at market price, the goal has been to identify what barriers impede adoption, and

Global Food Security, the International Food Policy Research Institute, the Center for Effective Global Action, and Innovations for Poverty Action. This paper has benefited from the input of David Levine, Dan Kammen, Margaret Torn, Ted Miguel, Alex de Pinto, and many fellow students and seminar participants. The project underlying this paper owes thanks to Paul Manda, Salim Shaban, Eric Solomonson, David Guerena, Jason Aaramburu, and many others, particularly at IPA-Kenya, which implemented the project.

how those might be overcome [21]. These barriers vary in scale from those mediated by national policy (land and labor market factors, infrastructure, etc.), to those that are more microeconomic in nature, such as information, credit availability, risk preferences, and other behavioral factors. A large and growing body of research – often using experimental methods – has found that relaxing these micro-scale barriers has substantially stimulated adoption, while elucidating mechanisms by which they have worked.

This paper makes three main contributions: first, I compare the efficacy of (1) simple price subsidies, (2) measures to stimulate social learning, and (3) novel sales offers aimed at reducing risk and overcoming liquidity constraints. While each of these has been shown to work on their own, it isn't clear what their relative efficacies might be as compared with one another; such an understanding can inform program design. Consistent with much other social network literature, I find a u-shaped relationship between the odds of uptake and the share of the network that is treated, with marginal effects that are stronger than those of price when few adopters are in the network. However, given low absolute uptake at no subsidy, this network effect is of little practical magnitude without substantial subsidies.[2] Second, I provide the first rigorous evaluation of the agronomic utility and livelihood benefits of biochar in smallholder agriculture – a "climate-smart" agricultural technology that may have potential to sequester carbon both while improving crop yields directly and improving marginal returns to fertilizer. I find that yields on farmers fields are consistent with, or greater than, results from agronomic studies. Third, I provide one of the first experimental adoption studies to be applied to technologies at the interface of agriculture, environment, and development. A central goal of this study is to provide guidance on how environmental (commonly carbon) finance can be used most efficiently to achieve environmental goals and improve livelihoods of potential adopters, where such projects depend on technology adoption. I find that a combination of heavy subsidies and measures to stimulate social learning maximize social return on investment, but that the amount of carbon sequestered by biochar is insufficient to support to justify the cost of programs to stimulate its uptake based on its carbon benefit alone.

As for biochar itself, it is unambiguously profitable in expectation, for an average farmer, at costs consistent with its sustainable provision by a profit-making business. As such, low observed uptake is well below what would be socially optimal. Given responsiveness of uptake to price, as well as the modest social network effect, I show that heavy subsidies coupled with demonstration plots would lead to social return on investment as high as 10% in this context – more if the social benefit of sequestered carbon is included. However, the amounts of carbon sequestered are not sufficient to justify its subsidy solely in terms of its global benefits.

After introducing biochar (section 1.1), I provide a brief literature review of the development economics literature in this space (section 1.2). I then describe the context and experimental design

[2]These conclusions are based on logistic models of uptake, which are described in further detail below. As such, marginal effects are interpretable as multiplicative odds ratios, with their effects on absolute probability being dependent on baseline probabilities, which depend on other factors.

(section 2), including a brief treatment of the semiparametric statistical methods that I use (section 2.2). The dataset is described in section3. I then provide results (section 4) and conclude with a brief discussion (section 5) focused on implications for policy and for further research.

1.1 Biochar

Biochar is the product of thermal decomposition of biomass in the absence of oxygen [22]. Termed "pyrolysis," the process of its production can be given by the following heuristic reaction:

$$CH_2O + \text{Heat} \rightarrow \mathbf{BC} + H_2 + CH_4 + \text{Heavier hydrocarbons}$$

In essence, heat drives flammable gases and vapor-phase hydrocarbons from biomass (approximated as CH_2O), while the solid that remains is chemically altered, forming black carbon.[3] The key distinction between this process and the process of simple combustion is the absence of ambient oxygen. Absent oxygen, a substantial portion of the feedstock remains in solid form, while heat alters the chemical structure of the remaining carbon atoms into increasingly condensed aromatic structures[4] with increasing temperature. There is no formal distinction between biochar and charcoal, either chemically or in their manner of production. Rather the two are differentiated by their intended end-use, though many forms of charred biomass – made, for example, from leaves, grass, or crop residues – would tend to be less useful as a fuel than would char made from large pieces of hardwood, which is more typically used for fuel charcoal.

Like other forms of nonliving organic carbon, biochar will "mineralize" over time, reacting with oxygen to form carbon dioxide. However, biochar does so much more slowly than the dead plant matter from which it is formed [29–31] – decomposing over timescales ranging from centuries to millennia. Early interest in biochar was catalyzed by the discovery of surprisingly fertile, dark-colored soils in the Brazilian Amazon, which were surrounded by highly weathered and much less-fertile soils [32]. These soils, which are coincident with pre-Colombian population centers, contain carbon dated to several centuries before European contact. Their fertility is attributed largely to addition of biochar, likely via produced by smoldering combustion during the process of land-clearing for agriculture [33–35].

By slowing the reversion of plant carbon back to the carbon dioxide from which it was formed,

[3] Detailed treatments of this process – of which the production of fuel charcoal is a special case – can be found in Brown [23] and in Antal & Gronli [24].

[4] "Aromatic" carbon refers to carbon that has formed a hexagonal ring of 6 carbon atoms. "Condensed" aromatic carbon refers to collections of ring structures that have fused to one another. Graphene occurs when aromatic carbon is perfectly condensed into sheets of attached rings, while graphite is formed when these sheets layer onto one another. The degree of aromaticity (i.e.: the proportion of carbon in aromatic clusters), and the degree of condensation (i.e.: the proportion of ring vertices that are bonded onto other aromatic rings varies with a number of parameters of the biochar production process, especially the temperature of production, which typically varies between 300°C and 750°C. Biochar is substantially more aromatic that living plant carbon, but substantially less so than graphene. See the following for more on biochar's chemistry: [25–28].

biochar suggests itself as a means of climate change mitigation via soil carbon sequestration. Woolf et al. [36] estimate that technical potential for mitigation with biochar may be as high as 10% of current emissions. Of course, the gap between technical potential and realized potential will depend on deployment and use of biochar production technology, which will in turn depend on economic feasibility. Biochar's costs are generally comprised of (1) the opportunity cost of the feedstock biomass, (2) capital costs of the equipment used to perform pyrolysis, (3) labor costs required to perform pyrolysis, and (4) transportation costs inherent in moving biomass to the equipment and biochar from the equipment. These costs vary substantially by context and by the type of technology used.

On the other hand, biochar's economic benefits are largely a function of its ability to improve crop yields. Meta-analysis of agronomic studies shows that average yields increases range from 5% to 30% over un-amended controls, with relatively higher increases in the weathered soils typical of much of the tropics, and lower to negative yield increase in the richer soils that make up much of the world's more important food-producing areas in the temperate zone [37–39]. Similar to other forms of soil organic matter (SOM), biochar can improve soil fertility across a number of dimensions – improving water holding capacity and soil structure, while reducing acidity and improving fertilizer-use efficiency [40, 41].[5] Importantly, these results have been shown to manifest immediately after application, and also to persist over multiple seasons beyond the season of initial application, offering the prospect of durably increasing soil fertility.

1.2 Technology Adoption in Developing-World Agriculture

Biochar appears to offer the prospect of improved agricultural productivity, both directly and via intensification through the improvement of marginal returns to inorganic fertilizer. This prospect is particularly attractive given both that biochar may contribute to climate change mitigation, and that this mitigation potential might justify carbon finance to support dissemination. However, diffusion and adoption of new agricultural technologies has proven to be a slow and uncertain process, particularly in sub-Saharan Africa [20, 21]. While profitability of new technologies has been shown to often not be as great as is commonly supposed [7–9], demonstration of economic benefit where it exists is insufficient to guarantee rapid dissemination and widespread adoption [42].

Despite of several decades of scholarship on the topic, it remains unclear how to stimulate dissemination efficiently. Early canonical papers tended to focus on the long-term patterns of technology diffusion, which they characterized using logistic models – slow early dissemination among innovators, followed by acceleration as the innovations caught on with more farmers, followed

[5] While the sole meta-regression analysis of plant response to biochar did not find evidence that biochar improved plant response to fertilizer [37], that study did not explore potential heterogeneity in mediators of response, and it is possible that it may do so in some contexts and not others. I will test for evidence that it does so in section 4.1 below.

by a deceleration as more recalcitrant farmers begin to adopt [43, 44]. While these works remain touchstones in the literature, their key insights provide relatively little guidance to actors seeking to speed the rate of diffusion.

From independence to the 1980s, subsidies were the major tool used to stimulate diffusion of hybrid seed and inorganic fertilizer in sub-Saharan Africa. Faced with criticism for being inefficient, costly, and potentially regressive, these subsidies were largely phased-out during the structural adjustment era, which saw an end to the growth in fertilizer consumption which had characterized the region in the 1960s and 1970s [45]. During their heyday, fertilizer subsidies were justified using some of the main hypotheses driving empirical technology adoption literature in more recent years [46, 47], particularly that provision of subsidies would encourage learning-by-doing, and thereby stimulate demand at market prices [48]. While blanket subsidies tend to be poorly targeted, and potentially inefficient [49], it is not always clear what alternative programs might work better. At minimum, the change in adoption with increasing subsidy can be used as a baseline with which to measure the efficacy of alternative measures.[6]

The fact that subsidies are costly has led to their justification on grounds other than simple dissemination; including the learning-by-doing argument mentioned above, as well as concerns for the welfare of poor farmers [50]. However, substantial research has also focused on whether demand might be stimulated in more cost-effective ways – potentially freeing resources for programs that might address welfare more directly. In particular, I focus on (social) learning and on novel sales offers designed to simultaneously remove risks and alleviate liquidity constraints. If equal rates of dissemination can be achieved by stimulating social learning or providing these novel offers, as compared to subsidy programs, then such programs should be considered preferable as they would free resources for other development priorities.

Social learning and technology adoption has been a popular topic in the field for the last two decades. Beyond interest in furthering economic theory – social learning is notoriously difficult to distinguish from imitation and correlation [51] – interest is often motivated by the observation that technologies that achieve high rates of penetration weren't generally subsidized and seemed to spread virally, with the rapid spread of cellular phones in the region commonly serving as an example. Several recent studies, often based on field experiments, have measured the effect of adoption among social network contacts on own-adoption. Most find large effects [52–56] – on the order of 20% increase in adoption rates among those with treated contacts or neighbors, though others find more modest effects [42, 57, 58]. In particular, the relationship between adoption and the number of social network contacts with a technology is commonly u-shaped – social effects have been strongly positive when there are few adopters in a network, before declining and becoming negative at high levels of adoption, for non-adopters – though different studies find turning points

[6] Recent years have seen a resurgence in agricultural subsidies under the umbrella of "smart subsidies," which seek to improve targeting and efficiency as compared to experiences of post-independence period [50].

at different locations [52, 53, 55, 57]. What's more, several of these studies have found that social effects work in some contexts but not others. Munshi found that social effects were stronger stimulating uptake of hybrid wheat than hybrid rice, arguing that wheat-producing areas were more environmentally-homogeneous than rice-producing areas, making learning easier in the presence of imperfect information about the mediators of the new technology's benefit. Krishnan and Patnam find substantially stronger social effects for seed adoption than for fertilizer adoption. Conley & Udry find that the social effects of "bad news" about a combination of inputs are stronger than "good news" about a combination of inputs. Finally, Duflo, Kremer & Robinson find that social effects are strong in the first year, but disappear in subsequent years – which is the opposite of what was found in Krishnan and Patnam's context, where the effects of extension[7] faded over time while social effects persisted.

Some of these studies distinguish between social learning via transmission of information about benefits of technologies, and social influence via imitation and herding [60], while others haven't. In general, a correlation between adoption in a network and one's own adoption could come either from learning or from imitation, in contexts where it is possible to exclude the possibility that results are driven by correlated unobservables. Distinguishing this effect is useful from the perspective of economic theory, but it may also have relevance for technology dissemination policy: where benefits of a technology are variable and/or highly mediated by imperfectly-known contextual factors, signals from contacts about benefits – which might lead to (or inhibit) adoption – will have an ambiguous effect, while herding effects might not be welfare-increasing for everybody. If Conley & Udry's finding that bad news travels faster than good news has substantial external validity, then technologies that are beneficial in expectation but highly variable might disseminate quite slowly if social learning dominates herding.

For technologies with particularly heterogeneous benefits, learning from experience might be preferable to learning from others. Yet poor farmers may balk at the risk inherent in investing in a technology with unknown outcomes, and/or they may simply lack the liquidity needed to do so. Technologies may be offered in such a fashion that these potential barriers no longer bind. Given that such offers involve a cost to the entity sponsoring them, they can be considered preferable to a simple subsidy where the cost of provision is lower than the cost of the subsidy, for a given level of adoption within a population.

In this study, I offer some farmers biochar for sale on a "free trial" basis – farmers receive a small quantity of biochar for a price, but are told that they can elect to pay for it or not at harvest. If they

[7] With exceptions [55, 59], studies of social learning and technology adoption in agriculture have dealt with traditional agricultural extension in little more than passing. This is largely a function of the developing-country context of the work, where extension services often have insufficient reach, and "model farmer" models seek to disseminate innovations to wider populations through first deploying the interventions to selected farmers, and then relying on social learning. Genius et al. find the two approaches to be complimentary, while Krishnan & Pattam find the extension has a much smaller effect than social learning. On the other hand, Maertens [57] finds that learning from authoritative sources is far more predictive of adoption than is the number of farmers in a network who have adopted.

pay, then they can continue to purchase biochar in subsequent seasons. If they do not, then they will be excluded from future biochar sales. Similar work includes Levine et al.'s [61] work on improved cookstoves in Uganda. They find that the combination of time-payments (addressing liquidity constraints) with the right to return (addressing risk) the promoted stove led to 42 percentage points more adoption than control groups. While there isn't much literature on these sorts of novel offers, they represent the combinations of a number of mechanisms, each well-studied in development economics. While such offers may not make sense as a business model for sustainable provision of a technology in many contexts[8], they may represent a means of increasing demand by stimulating learning from experience, and it seems possible *a priori* that they could be more cost-effective in doing so than simple subsidies, if they are better at increasing uptake and are repaid at high rates.

2 Context, experimental design, and methods

I conducted this study in rural areas surrounding Bungoma, in Western Kenya. The region receives about 1600mm rainfall annually, distributed bimodally in a long and a short rainy season, with the former lasting approximately March to June and the latter from August to November. Agriculture in the region is dominated by maize and sugar cane production. The former is grown mostly for consumption, while the latter is a cash crop. Most farmers plant two maize crops per year, and yields in the short rains are typically half of those from the long rains. Soils in the region are relatively weathered [62]. Population density is higher than that in much of the rest of rural Africa, averaging 100-250 persons/km. Farm sizes average below 1 hectare, and fallowing – once common in the area – is now rarely practiced due to land scarcity.

The project started in early 2013 as a partnership with Re:char Kenya Ltd., a private business which sold simple biochar production equipment to farmers. Called the "Rutuba[9] kiln," their device was a top-lit updraft gasifier [23] fashioned from oil drums and sheet steel. While the Rutubas are effective producers of biochar from agricultural waste such as maize stalks and sugar cane leaves, Re:char was unsuccessful in stimulating sufficient demand to sustain its operations, and went out of business in mid-2013. While a number of operational issues may have contributed to this outcome, a central factor explaining their exit may have been the focus on selling the technology itself – at a price of 4000 Kenyan Shillings (KSh) ($47.1) – which was felt to be too expensive by many in the region. Furthermore, former Re:char staff speculate that many of the kilns were adopted by farmers who had the intention of using them extensively, but who then did not do so during the periods when excess biomass became available, during harvest seasons. At Re:char's exit, my project acquired their stock of Rutuba kilns. Rather than selling the technology directly to farmers,

[8] Beyond the simple business risk in non-repayment, the threat of exclusion from future sales breaks down when more than one vendor is selling the technology in question.

[9] "Rutuba" means "soil fertility" in Kiswahili.

I focused rather on selling the service of biochar production and application to farmers, as described below.

Before Re:char's entrance, some biochar dissemination work had been conducted by the African Christians Organization Network (ACON) – a small NGO based in Bungoma. ACON's work started in 2008, after good results were observed on small plots. ACON typically targeted self-organized community groups, who established biochar demonstration plots. After observing good results on these demonstration plots, training participants often moved on to use biochar on their own land.[10] Around the time of Re:char's entrance however, ACON's work shifted towards clean cookstoves – leaving my project as the sole purveyor of biochar in the region by mid-2013.

2.1 Experimental design

Because prior experience with either Re:char or ACON might have influenced adoption of biochar, I selected areas around Bungoma where neither organization had previously worked. Specifically, I took a number of random draws from a circle centered on Bungoma, excluded those points that were within 5km of areas where either Re:char or ACON had previously sold kilns or done demonstrations, and selected the first 4 of those remaining. A 2km^2 box was drawn around these points, and households within them were identified using satellite images. Figure 1 gives the locations of the four zones, and the households within them.

A timeline of the project's activities is given in figure 2. Following approximate identification of households via satellite, enumerators visited these points, identified which of those represented households, and conducted the baseline census. Because I'm interested in agricultural decision-making, I define the "household" unit as groups of people who farm separately. Families in this region are commonly polygamous, though some polygamous families farm separately, while others farm collectively. Thus a household could be a monogamous family, a polygamous family farming together, or one of several wives of a single husband who farm separately, together with the husband or separate from the husband, if he farms separately from his wives.

Beginning in August 2013, 75 farmers were selected at random to receive biochar demonstration plots.[11] Project staff asked participating farmers to identify a prominent 1/8th-acre portion of their farm – in the sense that it was relatively more visible to passers-by than other portions – to comprise the plot. Plots were divided into four portions – half was to get biochar[12] (which half got biochar

[10] Most ACON-trained farmers used biochar from one of three sources: (1) collection of charcoal fines (small pieces and dust) from charcoal sellers in the area, (2) partially-combusted residues of home cooking fires, and (3) home production of cooking charcoal (commonly produced for sale), and utilization of the resultant dust and fine particles as biochar. None of these sources is readily scalable, and quantities used by these early adopters were quite small – a factor motivating Re:char's entrance.

[11] Not all of the original 75 selected to receive the plots; out of the original 75, 7 people refused, leading us to select replacements for them. Implications of this are explored in section 3, below.

[12] While biochar production can be somewhat labor-intensive and mediated by skill (depending on the technology used), biochar application involves very little skill or learning – it is applied together with fertilizers at planting,

was decided with a coin flip), while the other half didn't. Each of these two halves was further divided in half; we encouraged farmers to plant a staple food crop in one, and any alternative crop of their choice in the other. On the biochar half, project staff applied 25kg of biochar, which is equivalent to an application rate of 0.5 tons per hectare. Plots were demarcated using twine and marked with signs indicating which had biochar, and which didn't (figure 3). Farmers were asked to treat both halves identically with respect to inputs and labor. The spatial distribution of the demonstration plots is given in figure 4. At harvest in December, project staff measured yields on all demonstration plots using a scale.

We conducted a midline survey in October and November 2013, which focused heavily on social network data. For each respondent, I selected 75 other fellow respondent households to ask about, with the probability that farmer i was asked about farmer j being inversely proportional to the physical distance between them. For each potential link, farmer i was asked if they knew farmer j, using nicknames, spouse names, and place names to help distinguish people with similar names. Where a farmer i indicated that s/he knew j, surveyors asked about a number of different sorts of linkages, for example how recently they had seen one another, whether they talked about farming, etc. These are detailed in section 3.

Beginning in late January 2014, enumerators randomly allocated sales offers to all households. This was done by visiting all households in the sample, and offering a selection of sealed, unmarked envelopes, each containing an informational flyer and a sales offer with a randomized price. Under the "service model," farmers were offered the service of having our team visit their farm with Rutuba kilns, and produce char from their crop residues[13]. The service model was offered at randomly-varying prices, for fixed-ratio denominations of 25kg per 1/4 acre. In addition, some farmers were offered a "free trial," whereby they could get a 1/4-acre biochar demonstration plot at the price that they drew, but for which they would not be obligated to pay until after the subsequent harvest. If at that point they did not feel that the result was sufficient to justify the expense, they were not obligated to pay. If however they wanted to buy biochar from us again, they were expected to pay the price that was contained in the envelope. Payment was expected shortly after harvest – in order to minimize liquidity issues – but was accepted at any time. This distribution of prices and free trial offers is given in figure 5. The maximum price – KSh1,250 per 1/4 acre, or KSh625/sack – was constructed with an approximate profit margin of 55% over the approximate production cost of KSh400/sack to simulate a business's margin. During this randomization surveyors also asked about the number of biochar demonstration plots observed, and the respondent's subjective impression of the relative yield on the biochar plot as compared to the control plot.

The final survey round began in August 2014, in which we conducted a second sales offer. As I'll describe in section 4, sales in early 2014 were low. I therefore changed the sales model in the

either in furrows or in small holes with seeds.

[13]Where sufficient crop residues weren't available, staff delivered biochar produced elsewhere.

second round. First, farmers were offered biochar in 25kg sacks (sufficient for 1/8 acre), which were delivered and applied for a random price, ranging from KSh50-400 (USD0.6-4.7), in increments of KSh50.[14] Unlike in the previous season, distribution of different subsidy levels was flat – more farmers were offered heavy subsidies. In addition, all farmers who had gotten a free trial in the previous season were offered a randomized discount on the cost of their free trial repayment, ranging from 50-90%.

Project staff weighted the harvests for all farmers who had gotten biochar for the 2014 long rains (in early 2014), from both the biochar portions, and the portions without biochar. In addition we collected plot-level data on fertilizer use, land size, and "selection" – asking farmers if the place where they applied the biochar was relatively less fertile, more fertile, or about the same as the portions of their land that did not receive biochar.

2.2 Semiparametric statistical methods

My analysis involves relating continuous treatment variables to non-gaussian outcome variables. To avoid biases stemming both from functional form and distributional form mis-specification, I extensively employ generalized additive models. Generalized additive models (GAMs) [63] are semiparametric generalizations of generalized linear models (GLM's). The general form is $g(y) = \mu = \boldsymbol{D'\theta} + \mathcal{F}(\mathbf{Z}) + \epsilon$ where $\mathbf{D}$ are variables associated with parametric slope coefficients and $\mathbf{Z}$ are variables represented non-parametrically. The function $\mathcal{F}(.)$ is commonly a sum of univariate smooth terms, but can also include smooth functions of more than one variable, which may be represented for example with tensor product interactions [64], which can be conceptualized as generalizing penalized spline models to grid-mesh structures in 2 or more dimensions. These smooth functions are typically represented by penalized splines; specifying $\mathcal{F}(.)$ terms using some spline basis, and choosing $\hat{\boldsymbol{\beta}}$ to minimize $||y - \boldsymbol{X'\beta}|| + \boldsymbol{\lambda\beta'S\beta}$[15], where $\boldsymbol{\beta}$ is here defined to include both $\boldsymbol{\theta}$ and the penalized coefficients associated with each spline term, and where $\boldsymbol{X} \equiv [\boldsymbol{D}, \boldsymbol{Z}]$. The smoothing penalty $\boldsymbol{\lambda}$ and the matrix $\mathbf{S}$ are constructed so that smoothing only applies to non-parametrically-represented terms, and there is typically a distinct smoothing parameter for each nonparametric variable, which I choose via the restricted maximum likelihood smoothing parameter selection criterion [65]. The result is a flexible model in which both the functional form and the degree of smoothing are data-driven. When continuous variables have nonlinear effects, GAMs can be clear improvement over parametric techniques; reducing bias compared to linear specification, and often using fewer effective degrees of freedom than polynomial expansions. Textbooks on GAM's include [66, 67].

[14] Rather than simply selling sacks of biochar, staff delivered them and applied them to soil as directed by the purchasing farmers. This was done to avoid the potential that a farmer who had randomly selected a low price could buy and resell to his/her neighbors at a higher price.

[15] This is for the gaussian additive case. For other distributions, GAMs are fit with penalized iteratively-reweighted least squares. See Wood 2006 [66] for a full treatment.

In the final survey round, I seek to relate takeup of biochar to previous-season biochar takeup, which is endogenous. I therefore follow Marra & Radice's extension of instrumental variables techniques into the GAM framework, using two-stage generalized additive models (2SGAM) [68]. This framework itself is an extension of the "control functions" framework developed by Heckman [69]. Briefly, the approach adjusts for endogeneity by controlling for smooth functions of the residuals of first stage regressions in the second-stage regression. To account for uncertainty in the first stage regression, the asymptotic variance-covariance matrix is calculated by drawing several simulates from the posterior of each first stage regression, generating new residuals based on these simulated coefficients, refitting the second-stage based on these residuals several times, and then taking the covariance of the coefficients of the second-stage fitted with the many simulates.

3 Data and descriptives

Summary statistics on the farmers in the sample are given in table 1. The sample is composed primarily of small farmers with low yields and little other income. Women are the main agricultural decisionmakers in about 1/3rd of households. Few say that they had ever heard of ACON, Re:char, or the Rutuba kiln, and few (5%) report ever using charcoal as fertilizer.

Fertilizer use is generally low – most farmers spend just over $77/ha/season, while the government recommendations in the region call for 125kg of di-ammonium phosphate (DAP) and 125kg of calcium ammonium nitrate (CAN) per hectare, which together tends to cost around $200. Fertilizer seems to be profitable on average, though there is substantial heterogeneity. Using recall-based pre-treatment data, I modeled gross profits (market valued maize minus fertilizer expenditure) as a function of fertilizer expenditure, controlling for farmer fixed effects, zone-by-time period dummies and a smooth function of land size. Fertilizer is profitable on average; the coefficient on fertilizer expenditure is significant and greater than zero. However, specifying the effect of fertilizer as a random coefficient suggests that fertilizer is only profitable in expectation for 71% of the sample, which is consistent with findings by others of heterogeneous profitability in the region [7–9].

3.1 Compliance and attrition

Of the 1115 people surveyed at baseline, 81 were selected to receive demonstration plots, 9 of whom refused. Five of these refused because they did not plan to farm in the 2013 short rains. Summary statistics disaggregated by demonstration plot status are given in table 2. Those who refused the demonstration plot are somewhat different from others, though these differences aren't generally statistically significant. There are however marginally significant differences in terms of bicycle ownership and having heard of the Rutuba – a factor that I control for throughout.

Over the course of the project after baseline, 168 farmers attrited – they either refused to be

surveyed or could not be found by the survey team during one of the subsequent rounds. Statistics from the baseline census by attrition are given in figure 3. There are non-ignorable differences; those who attrited are more likely to be male, less likely to be listed as a social contact, and report higher incomes – generally consistent with people who travel outside of the region semi-permanently for work. I control for each of these factors throughout.

3.2 Social networks

Social network statistics are given in table 4. The average farmer knew about one third of those that were asked about, but talked about farming with far fewer. The average farmer had seen the land of about 1/5th of those asked about.

I don't assume that a farmer who says that they know another farmer is known by that farmer – I assume a directed network. While the literature is dominated by analysis of undirected networks, assuming an undirected network is problematic in this context – of the 7953 instances where both farmer i was asked about farmer j and vice versa, the link was reciprocal only 67.6% of the time.

Inferences based on networks constructed from sampled nodes are generally biased [70]. I avoid this bias by imputing missing edges using their conditional expectations, predicted from the following mixed logit:

$$pr(link_{ij}) = \Lambda \left[\alpha + \begin{bmatrix} \text{Same church}_{ij} \\ \text{Same school}_{ij} \\ \text{Gender}_i \\ \text{Gender}_j \\ \mathbf{1}\left(\text{Gender}_{i==j}\right) \end{bmatrix}' \boldsymbol{\gamma} + (\beta + \beta_i + \beta_j)\, log(\text{Distance}_{ij}) + \epsilon \right] \tag{1}$$

Model 1 represents the probability of linkage as a function of distance, at which certain individuals know and are known at different distances, and controls for gender of the household's main agricultural decisionmaker, observed membership in common churches, and observed attendance of their children in common schools. I fit model 1 for several dimensions of social network linkage, and the results are given in table 5. To varying degrees, distance[16] is a good predictor of social network linkage across all dimensions. Men report linkage more frequently, and are reported as known, more frequently than women. Farmers tend to know farmers of the same gender more often. Finally, people in the same church are more likely to know each other, as are people with children in the same school. These models are reasonably accurate – distributions of absolute prediction error (observed minus estimated probability) are given in figure 6, and are all less than 25% on average. I use these models to impute links with their conditional expectation where missing, which are

[16]Distance is represented in units of latitude/longitude, which are approximately equivalent near the equator, where Bungoma is located. 0.01 degrees of latitude is approximately 1km.

aggregated by respondent to calculate estimated links, given in table 4.

4 Results

Results are presented chronologically. I begin with demonstration plot yields, followed by biochar uptake in early 2014, followed by yield results from the 2014 long rains, followed by biochar uptake ahead of the 2014 short rains.

4.1 Late 2013: Crop yields on demonstration plots

Yield results on demonstration plots are shown in figure 7. On average, biochar plots performed substantially better than non-biochar plots. Assuming a maize price of \$392/ton (the approximate average retail[17] price during the project), biochar is profitable in expectation at a cost up to \$125/ha (KSh1083/quarter acre) for the average yields seen in these demonstration plots, and this expectation is positive at 95% confidence at a cost up to \$98.7/ha (KSh850/quarter acre). This is less than the cost of the most-expensive randomly-allocated price of KSh1,250 (\$14.7) per 1/4 acre, which is equivalent to \$145.3/ha.

Substantial variability in observed response to biochar suggests that biochar adoption might not be favored by risk-averse farmers. I explore this by determining what sorts of risk attitude are consistent with biochar adoption being favored or disfavored at a price of KSh850 per quarter acre, which is the highest price for which the expectation of biochar's profitability is significant at 95% confidence. I model the utility of adoption using a mean-standard deviation formulation following Saha [71], where $U(\mu, \sigma) = \mu^{\theta} - \sigma^{\gamma}$, and where the two exponential parameters control the degree of preference for distributions of different shapes. From the demonstration plots, average profitability is \$27/ha, with a standard deviation of \$140. Utility across a range of θ and γ is given in figure 8. At KSh850 per quarter acre, moderate levels of risk aversion may make biochar adoption an unfavorable prospect for those exhibiting declining average risk aversion[18].

Risk may be an important reason why a farmer might disfavor the prospect of biochar adoption, as it is quite profitable in expectation. It is unlikely that there are substantial hidden costs. Many novel agricultural technologies are labor-intensive, which involves cost beyond the cost of purchasing the technology [72]. Biochar does not require any additional labor for application beyond that which is used to apply fertilizer. And while any yield-increasing technology will increase weeding, harvesting, and processing labor requirements, it is also true that biochar's benefits in terms of durable yield increases and improved responsiveness to fertilizer are imperfectly observable. As

[17] The majority of the farmers in the sample consume the majority of the maize that they produce; very few sell in denominations larger than the 90kg sack. Thus I use retail prices for 90kg sacks, rather than bulk grain prices.

[18] Saha shows that $\theta < 1$ corresponds to declining average risk aversion, and that $\theta > 1$ corresponds to increasing average risk aversion.

such, it is not possible to exhaustively characterize all unobserved mediatiors of profitability, though it does not seem that biochar suffers from substantial hidden costs.

I explore mediators of observed demonstration plot results (for maize only) by fitting models of the form

$$\frac{\text{Biochar yield}}{\text{Control yield}} = g^{-1}\left(\begin{bmatrix} \text{DAP} \\ \text{CAN} \\ \text{Urea} \\ \text{mean previous yield} \\ \text{mean previous fert. exp.} \\ \text{Control yield} \end{bmatrix}' \boldsymbol{\beta} + \epsilon\right) \tag{2}$$

where $g(.)$ is identity or log, with Gaussian or gamma disturbances, respectively. Results are given in table 6. Unconditionally, the average biochar plot yielded 37% more than its control. On these demonstration plots, biochar increases response to fertilizer. Controlling for fertilizer, biochar does better on lower-yielding farms.

When asked, most farmers who hosted demonstration plots reported that the yields on the biochar portion were "very good" or "good" compared to the non-biochar portion of their plot (figure 9). When asked about the results of the demonstration plots on their neighbors farms, most farmers reported that they didn't know/see any demonstration plots. Those that did tended to say that the results were good or very good.

However, there is little correlation between reported qualitative impressions and measured relative increases, either for demonstration plot holders assessing the performance of their own plots, or for others assessing the demonstration plots of people that they know (figure 10), a finding that is largely invariant to which dimension of the social network is examined (table 7).

4.2 Early 2014: Biochar uptake

Of the 868 farmers who took an envelope containing a price and a sales offer in early 2014, 161 adopted biochar (18.5%). The adoption rate was 31.6% for those with a demonstration plot, and 63.9% for those with a free trial offer. Only 16 farmers adopted out of the 638 that did not get a free trial offer (2.6%). Of those that did, the average price was KSh293.75, which is a discount of 76.5% off of the full price of KSh1250 per 1/4 acre. A nonparametric univariate logit fit between price and uptake is given in figure 11.

There is little univariate correlation between biochar uptake and most social network measures. Figure 12 gives univariate logistic fits of uptake as a function of the share of each farmer's network with a demonstration plot, and of the number of links with a demonstration plot, controlling for the number of network links (following Kremer & Miguel [73]). Other dimensions of social network linkage are similarly non-predictive of uptake (table 8). Two exceptions are savings groups and

church groups; simple logits predict that having a larger share of one's church or savings group with demonstration plots is predictive of one's own uptake. I'm not able to exclude however that these results arise due to the multiple comparisons problem, as they are not robust to a Holm-Bonferroni correction.

I fit a logistic GAM to analyze the effects of the treatments together, including potential interactions between treatments. I control for having heard of Re:char and ACON, the gender of the household's main farmer, household income, whether the household reports having used charcoal as fertilizer before, and zone dummies. Given that I am agnostic about the functional form that the treatments take, as well as whether they are interactive, I performed a specification search algorithm to fit all possible parametric/nonparametric and interactive/non-interactive[19] representations of terms, preferring the specification that minimized AIC. Of those tested, the best-fitting model was

$$pr(adopt) = \Lambda\left[\alpha + \beta_1 FreeTrial + \beta_2 Demo + \beta_3 share + f(price, FreeTrial) + \boldsymbol{X'\theta} + \epsilon\right] \quad (3)$$

where the continuous-by-continuous interaction between price and the share of the network with a demonstration plot is represented with a tensor product interaction [64].

Results are given in table 9. The share of the social network having a demonstration plot is not a significant predictor of uptake, while those with demonstration plots are $e^{1.34} = 3.8$ times more likely to adopt biochar. Having a free trial increased adoption propensity by approximately 70%, while price was only a significant predictor for those without free trials, when they received the lowest possible prices.

These results are not driven by anchoring around neighbors prices, or the share of neighbors who got a free trial – figure 15 gives univariate nonparametric logit fits of the probability of adoption as a function of the average price in a network, and the share of the network that got a free trial.

For comparison, I provide an equivalent OLS regression, a parametric logistic regression, and a gaussian additive model in table 10 and figure 13. While results are qualitatively similar, there are some differences. In this context, F- and χ^2-tests indicate significant and insignificant ($p < 0.001, p = 0.47$) difference between the parametric and nonparametric gaussian and binomial (logistic) models, respectively. As is common with gaussian approximations of binomial distributions, these models give predictions outside of the [0,1] interval. In this context, estimates are reasonably robust to linear functional form assumptions and gaussian distributional form assumptions. This will not be the case with analysis of late 2014 adoption, given below.

Modeling probability of adoption as a simple function of the share of adopters in a social network ignores the content of the information transmitted through the social network. While average yield response to biochar on demonstration plots was quite large, there was substantial heterogeneity.

[19] Up to degree 2 – I don't check for the relevance of 3-way interactions.

It seems likely that farmers whose social contacts got poor results would be less likely to adopt biochar than farmers whose contacts got positive results.

I explore this by fitting a model similar to 3, but substituting observed outcomes of demonstration plots for variables representing their count. In particular, I use the response ratio (log(Treatment/Control)) of one's own demonstration plot, and the mean and standard deviations of the response ratios among social network contacts, fitting

$$pr(adopt) = \Lambda\left[\alpha + \beta_1 FreeTrial + \beta_2 RR_i + f(\mu(RR_{net}), sd(RR_{net})) + f(price, FreeTrial) + \boldsymbol{X'\theta} + \epsilon\right] \tag{4}$$

Results are given in figure 14. On ones own plot, high (low) demonstration plot response ratio is associated with higher (lower) propensity to adopt. Likewise, increasing average response ratio among social network contacts is associated with increased propensity to adopt. This propensity is declining in the standard deviation of this benefit however, such that high average results associated with large variability in those results are not associated with adoption. There are no observations of farmers whose network had high average yields and low yield standard deviation.

These estimates are biased if demonstration plot outcomes are endogenous. It is plausible that farmers who saw larger response to biochar may generally get lower yields, and thus be poorer, and thus be less likely to adopt biochar. Farmers who saw larger average yield benefits may be more likely to know farmers who tend to yield less, which could correlate with their own yields, which could correlate with their propensity adopt. I lack randomly-assigned variables that predict response to biochar[20], rendering IV strategies for surmounting this problem infeasible. I speculate that the estimated effect of observed mean in network is more likely to be biased downward than upward, given that I observe stronger yield response to biochar in lower-yielding farms than in higher-yielding farms, and lower-yielding farmers may tend to be poorer.

Finally, while there is a correlation between uptake and measured outcomes on demonstration plots, there is no correlation between uptake and reported perceptions of outcomes on demonstration plots. Re-specifying model 4 to include factor variables for own demo plot impression in place of RR and impressions of the plots of others in place of $\mu(RR)$ and $sd(RR)$ gives no significant coefficients on those factors. Thus, the results that were measured correlate with uptake, but the results that were reported do not.

4.3 Mid 2014: Biochar impact on maize yields

I have two sources of data on the impact of the biochar that was adopted in early 2014. First, staff directly measured yields on biochar-containing portions of fields of adopting farmers. They precisely measured the extent of their land, asked them how much fertilizer they applied to each portion of

[20] Note: such instruments might become available following results of the soil analysis.

their land, and whether the place to which they added biochar was "more fertile," "less fertile," or "about the same" as the parts without. Second, I have self-reported data for all farmers. The two datasets have different strengths and weaknesses. The former avoids the inaccuracy inherent in self-reported data, whether from poor short-term recall, error, or untruthfulness, though it is likely that there are variables which vary between plots for which I lack data. The latter may be affected by error in recall or deliberate untruthfulness, though its structure lends itself to clean identification of causal effects of biochar adoption via instrumental variables. I'll use both methods, beginning with the former.

4.3.1 Direct measurements

On average, biochar plots were 46% the size of non-biochar plots, got 25% less fertilizer, and were usually less fertile (49%) or of similar fertility (50%) as biochar plots. Yields on biochar plots compared to non-biochar plots are given on the left side of figure 16. On average, biochar plots yielded 0.5 ($\pm$0.25) tons/hectare more than non-biochar plots, with the difference being stronger where the non-biochar plots yielded less. This difference – modeling biochar yield as a gamma function of control yield – is higher at low yields and becomes insignificant where yields pass 2 tons/ha. Assuming a maize price of \$392/ton (the average during the project), expected profitability of a 0.5 t/ha increase in yield is about \$153/ha, above the highest of the randomly-allocated prices that was offered.

Given that farmers with biochar didn't manage biochar plots identically to non-biochar plots, this is likely a biased estimate of biochar's effect. I adjust for differences in how the plots were treated by fitting models relating yields to observed covariates, and then using these models to estimate what yields would have been had farmers used the same amount of fertilizer, the same amount of land, and the same quality of land. I begin by modeling

$$log(yield)_{ip} = \alpha_i + \sum_j f_j(\boldsymbol{X}_j) + \epsilon_{ip} \tag{5}$$

where p indexes plots (biochar or non-biochar), where $\boldsymbol{X}$ includes biochar use (as a dummy) interacted with DAP, CAN, and urea fertilizers, plot size, a factor variable for reported relative plot fertility. I then calculate adjusted yields as the fitted values of this model for mean levels of each covariate, plus the estimated residual, with the biochar dummy equaling 1/0 respectively. Adjusted data is plotted on the right side of figure 16. While this adjusted data is non-constant with respect to inputs and land size, at the mean levels of each covariate comprising the design matrix of 5, the mean difference between biochar and non-biochar plots is 1.6 t/ha ($\pm$0.16). As with the raw data, this difference diminishes and becomes insignificant as non-biochar plot yields increase, suggesting that biochar has it's greatest effect in low-potential agronomic environments.

As with the demonstration plots, most farmers report that they observed small or large positive differences between their plots with biochar and their plots without (figure 17, left). However, these reported impressions do not correlate with either raw differences between plots (not shown) or adjusted differences (figure 17, right).

4.3.2 Self-reported data

Estimating the causal effect of biochar adoption using self-reported data is more straightforward. I fit

$$\begin{aligned} yield &= \alpha + \beta BC + \boldsymbol{X'\theta} + \epsilon \\ yield_{it} &= \alpha_i + P_t + \beta BC_{it} + \boldsymbol{X'_{it}\theta} + \epsilon_{it} \end{aligned} \tag{6}$$

using cross-sectional and panel data (recall-based beginning in 2010), respectively. Because biochar adoption is endogenous, I instrument with the randomized inducements analyzed above: having a demonstration plot, the share of network contacts with a demonstration plot, price, free trial, and an interaction between price and free trial.

Estimates are given in table 11. Results are generally negative and not significant, in contrast to estimates from directly measured data. To explore this contrast, I plot measured yields against reported yields, as well as measured land size against reported land size, in the upper panel of figure 18. There is little correlation between what farmers reported and what was measured. While some farmers plant a portion of their maize on plots removed from the home area (where the biochar plot tended to be), which was not measured, this does not drive results – many farmers report having substantially less land than that which was measured. This finding – together with the finding that measured results of demonstration plots are significant predictors of uptake, while reported impressions are not – calls into question the accuracy of all self-reported data.

To further explore potential problems with self-reported data, I take advantage of an administrative error which saw several respondents asked the same questions multiple times. While several survey modules were duplicated, I focus on maize yields for the short rains of 2013 and the long rains of 2014. For each farmer who was given this module more than once, reported yield ranges (the difference between the maximum they reported and the minimum they reported) are given in the lower panel of figure 18. While most differences are small – likely representing approximation error – average differences are 82% and 102% of average maize yields for in the 2013 short rains and 2014 long rains, respectively. The magnitudes of these different answers to identical questions are not correlated with treatment status (having a demonstration plot, having biochar in 2014, biochar price, etc), nor are they correlated with membership in NGOs such as One-Acre Fund. This suggests that this misreporting is either simple approximation error (albeit very large error) or strategic behavior that doesn't vary systematically with any facets of this project – perhaps different farmers had different ideas of what our enumerators "wanted to hear." Irrespective of

potential explanations however, self-reported yield data is not trustworthy. And while much work in development economics relies on self-reported data, this result is not the first time that the accuracy of self-reported data has been called into question [74, 75].

4.4 Late 2014: Second round biochar adoption

The original experimental design emphasized adoption and impact in the 2014 long rains. However, uptake in that season was very low. It is possible that too-high prices masked effects of learning about biochar's benefits, either from own-experience in having had it, and from the experience of seeing it's impact on the plots of neighbors. These considerations guided the re-randomization of prices in August 2014, for the short rains agricultural season, as well as the offer of discounts for free trial repayment.

4.4.1 Free trial repayment

Of the 161 respondents with free trials, 19 repaid ahead of the 2014 short rains planting season, unconditional on the repayment price they faced, whether they planned on farming in the short rains, or other factors. I model propensity to repay as a function of several factors, reported in table 12 and figure 19. Only the free trial repayment price is a significant predictor of repayment, along with income. Neither the subjective impression of the result of the biochar, nor the measured result, are significant predictors of repayment.

4.4.2 Short rains biochar uptake

Between August and October 2014, 96 farmers bought biochar. Unlike the previous season, none had free trials. The average price at which biochar was purchased was KSh143 per 25kg sack, similar to the average price of KSh294 in the previous season, for double that amount. The two seasons are not directly comparable however; the short rains (in the second half of the year) are generally less important agriculturally. This suggests that demand should likely be lower than in the long rains, all else equal.

Some of the factors that might have played a role in inducing farmers to adopt biochar are now endogenous. The share of the farmer's social network that adopted biochar in the previous season is based on the share of that farmer's network that themselves chose to adopt biochar – a decisions that is likely correlated with the characteristics of those people, which in turn are likely correlated with the characteristics of their social contacts, which in turn are likely correlated with adoption. For the same reasons, previous-season adoption is also endogenous.

I instrument for the latter using the adoption inducements that were allocated randomly in early 2014, and the first stage is model 3. For the former, I use the network analogs of the randomized inducements – substituting the share of a given farmer's social contacts with free trials for the free

trial, the share of the network with a demo plot for having a demo plot, and the average price in the social network for the price faced by an individual farmer. The outcome – is modeled as a gamma GAM, and results are given in table 13. The share of the network with a free trial is the only significant predictor of the share of a given farmer's network that adopted biochar in early 2014, though it is a very strong predictor – the model explains 96% of the residual deviance.

For the second stage, I fit the following model:

$$pr(adopt) = \Lambda \left[\alpha + \begin{bmatrix} \text{Demo plot} \\ \text{BC 2014} \\ \text{Planted SR14} \end{bmatrix}' \beta + f \begin{pmatrix} \text{Share with demo} \\ \text{Share got BC 2014} \\ \text{Price} \\ \text{F.T. repay} \end{pmatrix} + \boldsymbol{X'\beta} + g_1(\hat{\nu}_1) + g_2(\hat{\nu}_2) + \epsilon \right] \tag{7}$$

where terms listed in red are endogenous, and functions $g(\hat{\nu})$ are functions of the residuals of the first-stage regressions, added to adjust for endogeneity. In addition, I check for interactions between the amount to be repaid (for those who had a free trial), and the short rains 2014 price, interactions between the share with late-2013 demonstration plots and the share adopting biochar in early-2014, and heterogeneity in response to the network measures why whether or not the respondent herself had biochar in early 2014.

Results are given in table 14. Across all specifications, only the price per bag of biochar is significant at $p < 0.05$, though the share of the network with biochar in early 2014 is marginally significant in specification 3, which also has the best AIC. I report marginal effects of significant and marginally significant terms for model 3 in figure 21. As price increases, the probability of adoption drops substantially. While the effect of the network share adopting biochar is noisy, there is suggestive evidence of a u-shaped relationship, whereby small numbers of adopters in a network stimulate adoption, and larger numbers inhibit it – similar to findings by others in literature on social influence and adoption [52, 53, 55, 57].

For comparison, I fit model 7 as a two-stage least squares (2SLS) linear regression, including a quadratic term for the share of the social network having biochar. Estimated social network effects, price effects, and comparisons of marginal effects between 2SGAM and 2SLS specifications are given in figure 20. The two terms comprising the quadratic social network effect are not jointly significant, though the effect of price is significant at $p < .001$. Estimated marginal effects of social network are substantially over-estimated and under-estimated with respect to 2SGAM estimates at different points in the distribution of the share of the network with biochar. It is clear that these differences in marginal effects are relics of the rigidity of the quadratic used to model the variable. Furthermore, the 2SLS specification estimates identical marginal effects across the range of network share, while these vary substantially with price in the 2SGAM. Concretely, the 2SLS specification suggests that propensity to adopt biochar increases by 50 percentage points as the share of the

network with biochar increases from 5% to 10%. This marginal effect is close to the 2SGAM logit estimate only when the price of biochar is at its maximum subsidy – in other price scenarios, the effect is overestimated. For the effect of prices, the differences between the two specifications largely reflect the particular parametric form of the logit link function, given 2SGAM estimates of near-linearity on the logit scale (table 14).

Marginal effects based on other specifications are qualitatively identical, but misleading – an additive gaussian model predicts a 20% increase in adoption propensity as the share of the treated social network expands from 5 to 15%, much as the logistic model does. However, this result for the logistic model is conditional on other covariates being held to their mean, while for the gaussian model this result applies to the conditional expectation in the sample. This is misleading, given that the sample was also heavily subsidized on average. As such, the conditional expectation for the sample cannot be interpreted as the expected marginal effect of change in the share of the social network with biochar for a particular farmer.[21]

Model 7 doesn't capture anything about the content of information transmitted in the social network; probability of adoption is related simply to the share of the network with biochar. Refitting this model to include statistics of (1) measured results within social networks and (2) reported impressions of results within social networks yields no result – neither the average network result nor its standard deviation predict adoption, nor does the reported impression of the results on the fields of those who got biochar.

In addition, I fit an equivalent model relating the number of bags of biochar purchased to the same set of predictors, modeled as poisson – those results are given in table 15.

4.5 Prospective impact of subsidies on welfare and carbon sequestration

The foregoing results do not directly compare the efficacy of funds spend subsidizing biochar versus funds spent stimulating social learning, either in terms of uptake, welfare, or social cost/benefit. I do so in this section, by taking conditional expectations of model 14 (poisson) across a grid of values constructed to represent hypothetical biochar subsidies and hypothetical expenditure on demonstration plots, using costs specific to this project's context. I do so for an "average" farmer – using average yield increase from late-2013 demonstration plots, average covariate values of model 14, etc.

First, I estimate the share of an average farmer's network with biochar as a function of the number of free trials in their social network, controlling for the total number of links in their network – analogous to the second of the first stage models for model 7, but using the number in the network rather than the share. That estimate at the mean of total links is given in figure 22a.

[21] This remains to be expanded. I'll present OLS, parametric logit, and additive gaussian models, showing qualitatively similar results. For the gaussian models, the estimated conditional expectation functions for the sample are easily misinterpreted as the conditional expectations for individuals, which they are not.

I then use that estimate to predict the average share of a network with biochar plots, had I chosen to give out a different number N of the free trials. I do so by taking the estimated probabilistic adjacency matrix $\boldsymbol{A}$ representing the social network, and for a gradient of values between N=1 and N=200, take 500 samples (without replacement) of farmers $\boldsymbol{g}$, where each row is a vector of N 1's and the rest zeros, for each farmer in my sample. This gives 500 different possible combinations of how the demonstration plots could have been allocated. I then calculate the expected number of links that a given farmer would have with a free trial as the mean of the row-wise sum of $\boldsymbol{g'A}$. The mean and 95% quantiles of that distribution are given in figure 22b as a function of N. I use this estimate to go from share of network with biochar – which I model – to number of free trials which I could have potentially given out under a different program design.

The conditional expectation of the number of bags of biochar purchased by an "average" farmer – in the sense of mean values of all covariates – across a grid of subsidies ranging from free provision to full cost (KSh400/USD4.6 per 25kg bag), and number of demonstration plots ranging from 0 to 200, is given in figure 22c. The function is maximized at free provision, with approximately 15% of the population getting demonstration plots.

Figure 22d gives the welfare implications of the subsidy scheme for the average farmer. This is calculated as

$$\frac{\big((1-p)(\bar{y}) + p(\bar{y} * .37 - c^{bag} * bags)\big) - \bar{y}}{\bar{y}} * 100\%$$

where p is the proportion of the average farm (0.32 ha) covered by the number of purchased bags of biochar, $\bar{y}$ is the average gross revenue of maize production – 0.39 tons, at \$392/ton. Welfare is maximized where adoption is maximized – at free provision with about 15% of the network having a demonstration.[22]

Figure 22e gives social return on investment, defined as the difference between farmer welfare under the subsidy scheme and the baseline, less the cost of those subsidies. For provision of demonstration plots, I assume that each costs double the cost of the biochar itself – a rough estimate based on this project's implementation costs – and divide the sum of these costs by the number of farmers in the sample. Costs of subsidies depend on expected uptake. I find that social return on investment is maximized at subsidies that induce maximal uptake, topping out at 10% return on investment. Social ROI per dollar program expenditure is given in figure 22f. This function is trivially maximized at zero demonstration plots and modest subsidies. However, there is very little uptake in this region of the function, and social ROI per program dollar in higher-uptake regions is maximized at higher subsidies and substantial provision of demonstration plots.

Incorporating carbon finance changes the locations of the optima little, though different as-

[22]Note that estimates at free provision involve extrapolation between the maximum subsidy that was experimentally provided – 87.5% – and 100%. While nonlinearities in response in this interval can't be excluded, the optimum with the rightward part of the figure removed still involves maximal subsidies and about 15% of the network having demonstrations.

sumptions affect their magnitude. I assume that biochar is half carbon by mass, and that 80% of this carbon is "stable," and that carbon is valued at $100/ton. These are generous assumptions – particularly on carbon price and on biochar's stability. However, even holding these, the location of the social optimum subsidy scheme changes little (figure 22g), nor does the carbon price pay for the program cost at the social optimum (figure 22h). In general, it appears that the impact of a carbon price on the attractiveness of expenditure on biochar subsidies is marginal, though biochar subsidies might be justified purely on a welfare basis.

5 Discussion

This experiment yields seemingly contradictory results. Where directly measured, biochar leads to substantial crop yield increases. However, I find no effect (and negative point estimates) when analyzing self-reported survey data on yields, or self-reported subjective impression of yield. It is difficult to avoid the conclusion that there may have been substantial survey nullification. In other words, farmers may have strategically told enumerators whatever they felt might be advantageous, based on what they supposed that the priorities of the project might be.

Anecdotally, enumerators reported that many respondents conflated the project with One Acre Fund – a prominent NGO operating in the region that offers agricultural inputs on credit. Many farmers in the region believe that OAF repossesses assets in the event of non-payment, though this practice isn't consistent with OAF's policies. On the other hand, OAF doesn't generally collect on loans when correlated shocks – such as poor rainfall – occur. This fear of debt, conflation of us with OAF, and perception that we might not expect repayment if results were poor, could have contributed to the divergence between what was measured and what was reported. While plausible, this is little more than speculation.

Uptake results are equally contradictory, though in different ways. Of the interventions implemented, the novel offers were the most effective in stimulating uptake. They were generally not repaid however, even when farmers measured outcomes to adoption were favorable. I find no evidence that demonstration plots within a social network led to more uptake in the first season, though there is evidence that having a demonstration plot made uptake more likely. In addition, we find weak evidence that demonstration plot results – both on one's own farm and on the farms of others – were associated with higher uptake, though this result may be contaminated by omitted variables. Nonetheless, it stands in contrast both to the fact that free trial repayment was uncorrelated with measured results, and to results observed in the following season – in which network share with biochar *was* significantly correlated with uptake in some specifications, but observed (and reported perceived) outcomes were not.

Unsurprisingly, price was a significant predictor of uptake in both seasons. More farmers bought biochar in the second season (96 vs 16), and the estimated functions mapping price to probability of

adoption changed from one that where farmers were unlikely to buy at any price, to one where the probability of adoption declined steeply with price. It is unclear what caused this change, though it seems likely that the efficacy of social learning and/or social influence changes with time, in ways beyond that in which time is a proxy for information gathering from one's social network or other sources. Longer longitudinal studies are needed to elucidate these dynamics.

5.1 Implications for diffusion theory

Our estimates of the significance and magnitude of social learning were within the range of previous estimates – it was significant in the second season but not the first, and where it was significant, it's influence was u-shaped. In particular, I find evidence that uptake in the first season was related to measured outcomes, suggesting social learning played a stronger role than social influence. I don't have an explanation of why this finding is reversed in the second season, and further work should elucidate when and whether influence or learning dominates.

The main contribution with regard to technology diffusion is a comparison of the relative efficacies of subsidies and social learning. While the marginal effect (in terms of odds ratios) of increasing the proportion of a social network with biochar is steeper at low penetration rates than is the marginal effect of subsidies, the baseline probability that biochar is adopted is sufficiently low as to render this estimate economically insignificant. Where biochar is heavily subsidized, baseline probability increases sufficinetly that these social network effects can take hold.

Had I fit an additive gaussian probability model,[23] I would have found a positive and significant marginal effect on the order of a 10% increase in probability of adoption, as the share of the network with biochar increases from 5% to 10%. This would be a valid approximation of the conditional expectation for the sample, for which prices were randomized and hence orthogonal to the share of the network with biochar. But, had I not used a logit, this approximation may have led to the misleading conclusion that measures to stimulate social learning are more effective than subsidies. While this may be true in terms of odds ratios, it ignores that adoption absent subsidies is sufficiently low as to render these increased odds irrelevant. Future studies on technology adoption may benefit from use of limited dependent variable models to avoid these sorts of pitfalls.

Adoption per dollar of program expenditure is maximized at heavy subsidies with relatively low numbers of demonstration plots, and, conditional on sufficient subsidy that the expectation of number of bags adopted is greater than 1, minimized at high numbers of demonstration plots and lower subsidies. Social learning seems to have an important role in mediating response to subsidies, though further work in other contexts is needed to lend this conclusion external validity. In particular, I find no interaction between price and the treated share of the network, suggesting that the complementarity that I find owes more to subsidies lowering the price sufficiently as to

[23] In other words, a semiparametric version of a linear probability model.

make the object of learning indeed become worth considering seriously.

Further work is needed to place these results into a more dynamical context – to what degree can a "big push" of subsidies over a few years sustain long-term adoption, with adoption over time sustained by social learning? Given that price sensitivity and response to the social network changes over time, this queston may be worth asking. While the post-independence experience with fertilizer suggests that the answer will not be that it can do so perfectly, it seems likely that the result is also nonzero. Furthermore, while a u-shaped social influence function is observed here as elsewhere, it seems unlikely that it would persist over multiple seasons, particularly given that it has been explained elsewhere by strategic learning externalities.

5.2 Welfare implications of biochar subsidization

In increasing yields substantially, sequestering carbon, but yet being underadopted, biochar is a prime candidate for programs aimed at stimulating its adoption. In this project's context, it appears that heavy subsidies maximize social benefit/cost per dollar, along with a small number of demonstrations. In addition, these estimates of social ROI are almost certainly underestimates, given biochar's complementarity with fertilizer, as well as the longevity of its agronomic benefits observed in other studies. However, here as elsewhere, external validity needs to be established via replication in other contexts.

6 Conclusion

I've conducted the first randomized controlled trial on the adoption and impact of biochar in smallholder agriculture, and found substantial agronomic utility, severely sub-optimal rates of adoption, and some evidence to guide technology diffusion policy. It appears that social learning can play a complimentary role in technology dissemination policy, but relying on it as a means of shortcutting the high cost of subsidies is likely to be misguided. It can, however, make subsidies more effective, and should probably be viewed in this light. I find no evidence that deferred payment offers are effective in stimulating uptake, though this finding, together with substantial inaccuracy in self-reported data, suggests that this result might arise more through strategic behavior on the part of respondents than the inefficiency of the approach as such. Together, these results demonstrate substantial potential for biochar in African agriculture – even irrespective of its value in climate change mitigation – they suggest means of promoting it, and as such could guide approaches for further applied research and program development in the area.

7 Figures and Tables

Figure 1: Locations of the four zones in which the project operated, in relation to each other and Bungoma town. Dots represent households in the study. Inset map shows Bungoma's location in Kenya.

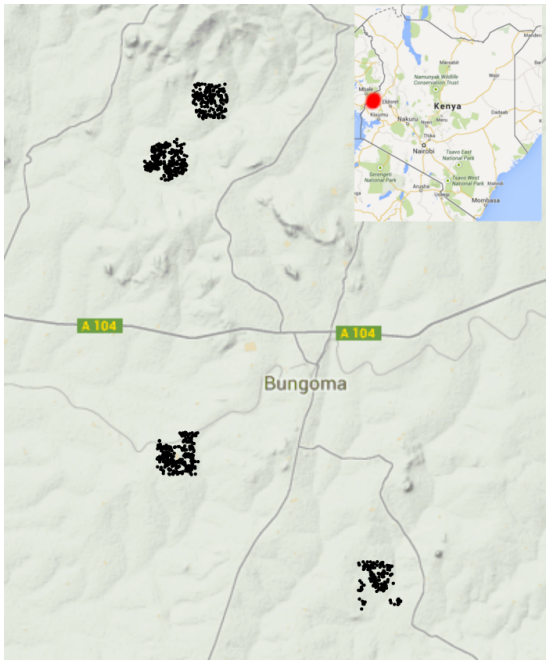


Figure 2: A timeline showing project activities and the region's agricultural calendar.

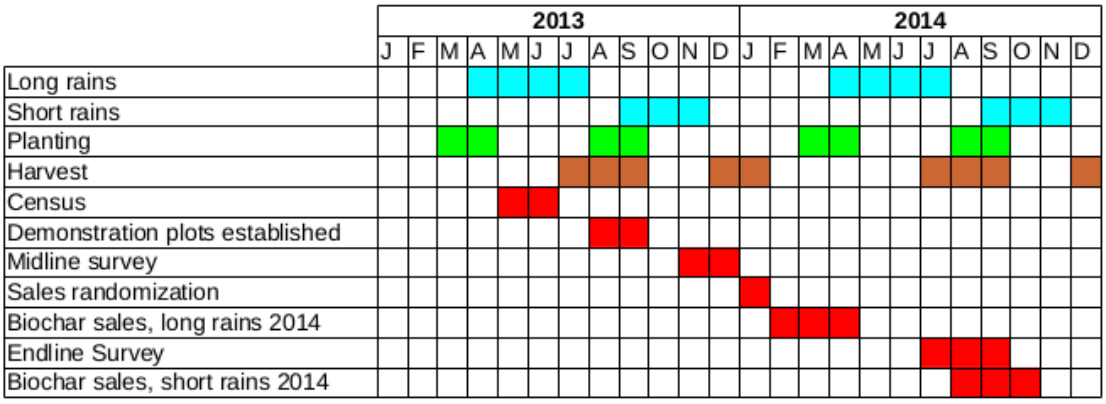


Figure 3: Signs placed on biochar demonstration plots. “Bila” means “without” in Kiswahili.

Table 1: Summary statistics describing the sample. Time-varying agricultural variables (yields, land allocation, etc. taken from the long rains 2013, before any of the treatments were implemented.

Statistic	N	Mean	St. Dev.	Min	Max
Maize Yields (tons/ha)	864	1.093	0.807	0.000	3.336
Hectares Maize	864	0.349	0.320	0.051	3.237
Hectares Sugar	889	0.099	0.262	0.000	3.642
Total Land (ha)	889	0.560	1.752	0.000	50.990
Fert Exp ($/ha)	887	78.388	72.063	0.000	374.437
Income (Sep 2014)($/month/household)	895	61.788	108.321	0.000	1,458.824
Family size	911	5.888	2.485	1	16
in OAF[24]	914	0.229	-	0	1
Gender main farmer (0=female)	914	0.345	-	0	1
Heard of Re:char	914	0.038	-	0	1
Heard of ACON	914	0.091	-	0	1
Heard of the Rutuba Kiln	914	0.051	-	0	1
Ever used charcoal as fertilizer	914	0.05	-	0	1
Ever produced charcoal	914	0.326	-	0	1

Figure 4: The spatial distribution of the biochar demonstration plots, established in August and September 2013. Each zone is approximately 4km^2.

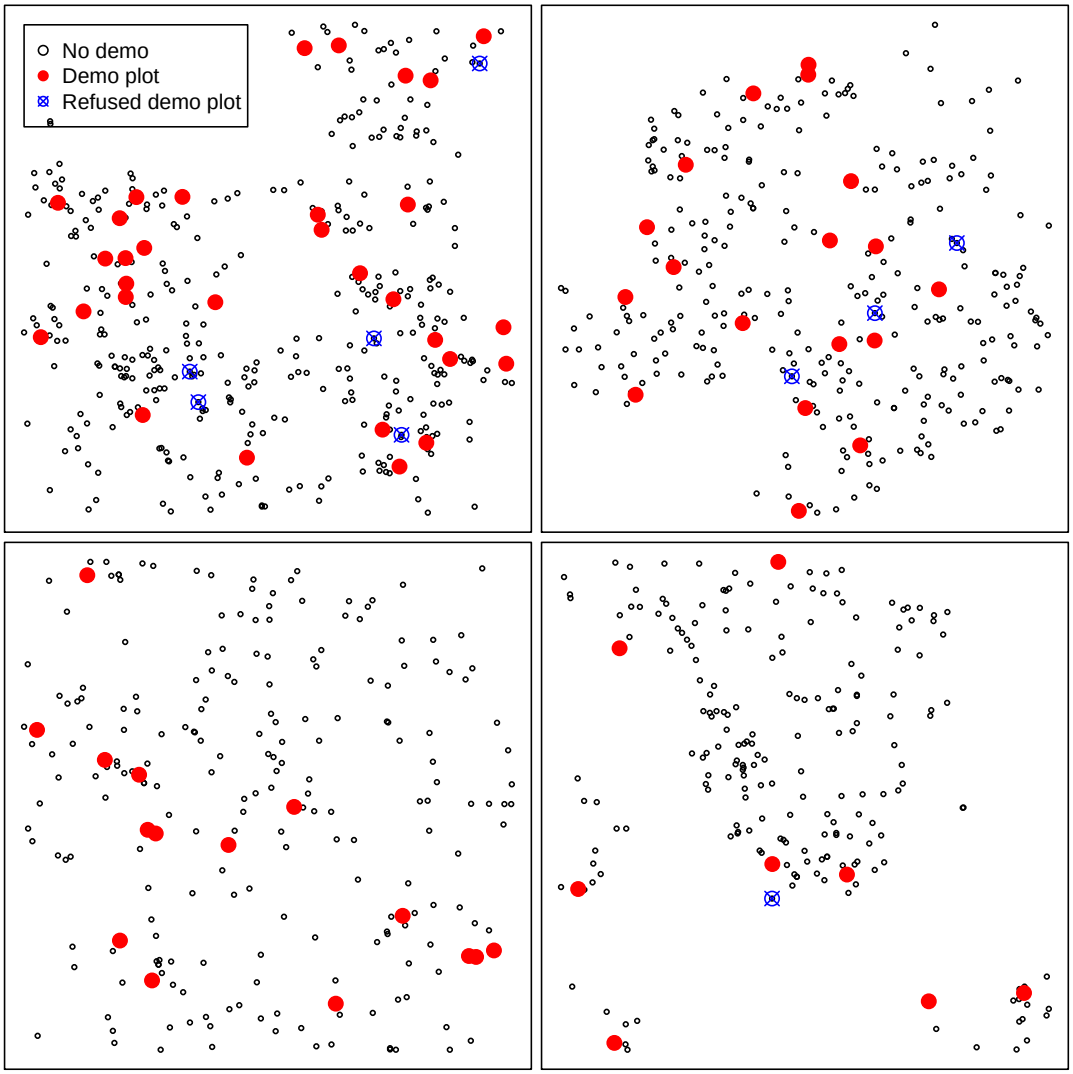


Figure 5: The distribution of biochar prices and free trials offered in the 2014 long rains season.

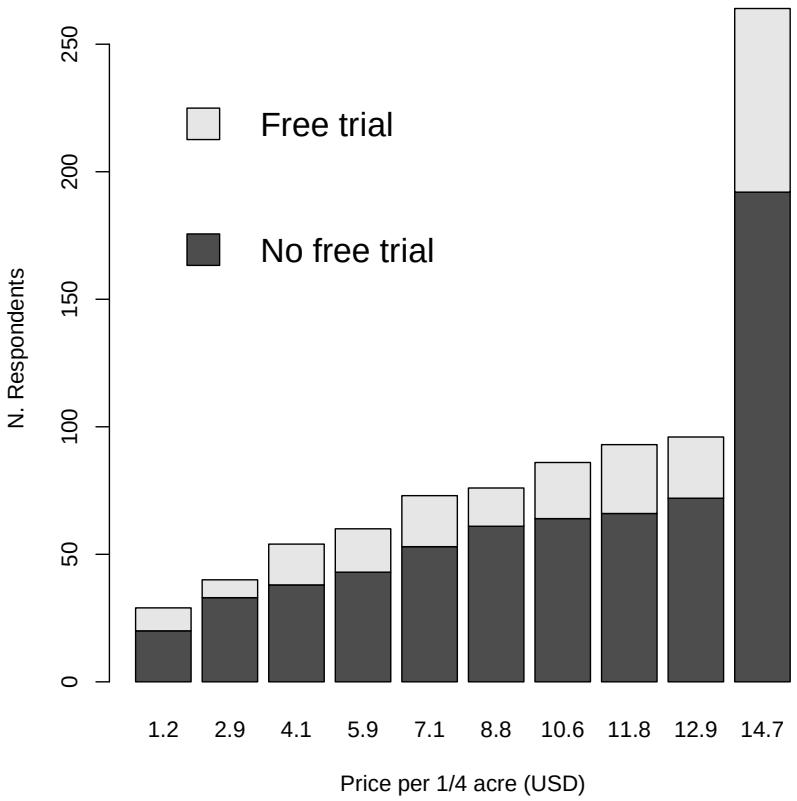


Table 2: Comparison of summary statistics by demonstration plot status; taking a demonstration plot, not being offered a demonstration plot, and refusing a demonstration plot. The sixth and seventh columns respectively give the p values of the differences between those with and without demonstration plots, and the differences between those with, without, and refusing. The latter are p-values associated with F-statistics.

	All	Got demo	No demo	Refused demo	p(diff(1,2))	p(diff(1,2,3))
N	1115	72	1034	9	-	-
gender (male=1)	0.25	0.28	0.24	0.11	0.53	0.53
Maize yield (t/ha)	1.34	1.30	1.34	1.79	0.71	0.25
Maize hectares	0.35	0.31	0.35	0.48	0.28	0.28
Beans yield	0.23	0.25	0.23	0.10	0.58	0.51
Beans hectares	0.33	0.29	0.33	0.76	0.34	0.02*
Fert. exp. per hectare	88.97	87.40	88.95	103.98	0.86	0.82
Acres sugar	0.10	0.11	0.10	0.01	0.72	0.62
Number listing as social contact	92.73	93.94	92.59	99.13	0.83	0.91
Eigenvector centrality (inbound)	0.21	0.25	0.21	0.23	0.11	0.26
Distance from center of zone	0.01	0.01	0.01	0.01	0.47	0.76
Owns bicycle	0.62	0.46	0.63	1.00	0.09*	0.09*
Number of phones in household	1.11	1.08	1.11	1.33	0.78	0.74
Income per year at baseline	346.55	400.22	341.98	484.71	0.61	0.80
Owns motorcycle	0.07	0.10	0.07	0.22	0.49	0.35
Heard of Re:char	0.04	0.03	0.04	0.11	0.61	0.48
Heard of ACON	0.09	0.11	0.09	0.11	0.59	0.85
Heard of the Rutuba	0.05	0.10	0.05	0.11	0.09*	0.17
Has used charcoal as fertilizer	0.05	0.06	0.05	0.11	0.69	0.61
Has produced charcoal	0.33	0.40	0.32	0.44	0.14	0.26

Table 3: Comparison of summary statistics by farmers who attrited after the baseline survey, versus those who didn't. The last column gives the p-value of the difference between the two.

	All	Full Sample	Attrited	p
N	1115.00	947.00	168.00	-
Gender	0.25	0.28	0.05	<.01***
Number listing as social contact	92.73	94.01	85.54	0.05**
Eigenvector centrality (inbound)	0.21	0.21	0.22	0.73
Distance from center of zone	0.01	0.01	0.02	0.12
Owns bicycle	0.62	0.62	0.61	0.82
Number of phones in household	1.11	1.12	1.06	0.40
Income per year at baseline	346.55	327.09	460.08	0.09*
Owns motorcycle	0.07	0.07	0.05	0.36
Hear of Re:char	0.04	0.04	0.04	0.79
Heard of ACON	0.09	0.09	0.10	0.92
Hear of the Rutuba	0.05	0.05	0.06	0.72
Has used charcoal as fertilizer	0.05	0.05	0.04	0.47
Has produced charcoal	0.33	0.33	0.32	0.90

Table 4: Summary social network statistics.

Statistic	N	Mean	St. Dev.	Min	Max
Reported links	945	26.357	10.838	0	61
Estimated links	945	94.151	46.204	8.082	284.035
Rep. talked farming	945	7.180	8.375	0	55
Est. talked farming	945	20.613	26.468	0.258	237.993
Rep. seen land	945	14.520	9.818	0	59
Est. seen land	945	43.419	34.898	1.277	263.011
Rep. same church	945	5.608	5.849	0	29
Est. same church	945	20.765	20.445	2.124	119.939
Rep. same sav group	945	2.841	4.839	0	38
Est. same sav group	945	9.383	14.980	0.538	144.827
N within 1km	945	160.505	50.897	23	299

Table 5: Results of model 1 for different dimensions of social network linkage.

			In past month...			Know from...		
	Linkage	Talk farming	Seen	Seen land	Seen crops	Is a relative	Church	Savings group
(Intercept)	-10.67^{***}	-11.17^{***}	-10.65^{***}	-11.54^{***}	-11.38^{***}	-9.59^{***}	-7.87^{***}	-8.69^{***}
	(0.10)	(0.14)	(0.10)	(0.12)	(0.11)	(0.11)	(0.12)	(0.17)
In same church	0.51^{***}	0.75^{***}	0.52^{***}	0.71^{***}	0.58^{***}	0.68^{***}	2.80^{***}	1.39^{***}
	(0.04)	(0.06)	(0.04)	(0.05)	(0.05)	(0.05)	(0.05)	(0.07)
Kids in same school	0.20^{***}	0.18^{***}	0.20^{***}	0.15^{***}	0.15^{***}	0.18^{***}	0.23^{***}	0.21^{**}
	(0.03)	(0.05)	(0.03)	(0.04)	(0.04)	(0.04)	(0.05)	(0.07)
Gender_j	0.16^{*}	0.09	0.18^{*}	0.18^{**}	0.20^{**}	0.26^{***}	0.09	-0.02
	(0.08)	(0.07)	(0.07)	(0.06)	(0.07)	(0.07)	(0.07)	(0.08)
Gender_i	0.54^{***}	0.94^{***}	0.55^{***}	0.74^{***}	0.71^{***}	0.45^{***}	0.03	-0.28
	(0.08)	(0.14)	(0.08)	(0.09)	(0.10)	(0.09)	(0.08)	(0.17)
$\text{Gender}_i == \text{Gender}_j$	0.08^{**}	0.18^{***}	0.07^{*}	0.12^{***}	0.09^{**}	0.03	0.01	0.07
	(0.03)	(0.04)	(0.03)	(0.03)	(0.03)	(0.04)	(0.05)	(0.06)
$\log(\text{distance}_{i,j})$	-1.86^{***}	-1.34^{***}	-1.80^{***}	-1.73^{***}	-1.76^{***}	-1.21^{***}	-0.75^{***}	-0.67^{***}
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.03)
Log Likelihood	-27709.87	-13885.86	-27162.71	-21695.06	-23069.07	-17344.47	-12882.75	-7861.72
Deviance	55419.74	27771.73	54325.42	43390.12	46138.14	34688.95	25765.51	15723.44
Num. obs.	70950	71025	71025	71025	71025	71025	71025	71025
Num. groups: Asked about	1116	1116	1116	1116	1116	1116	1116	1116
Num. groups: Asked	946	947	947	947	947	947	947	947
Variance: $\text{ID}_j \times \log(\text{dist})$	0.05	0.02	0.04	0.02	0.03	0.03	0.02	0.02
Variance: $\text{ID}_i \times \log(\text{dist})$	0.04	0.12	0.04	0.06	0.07	0.05	0.03	0.12

$^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$

Figure 6: Distributions of absolute prediction error from estimates of 1 across multiple social network dimensions. Prediction error defined as $|\mathbf{1}(link_{ij}) - \widehat{pr}(link_{ij})|$. Dashed red lines represent means.

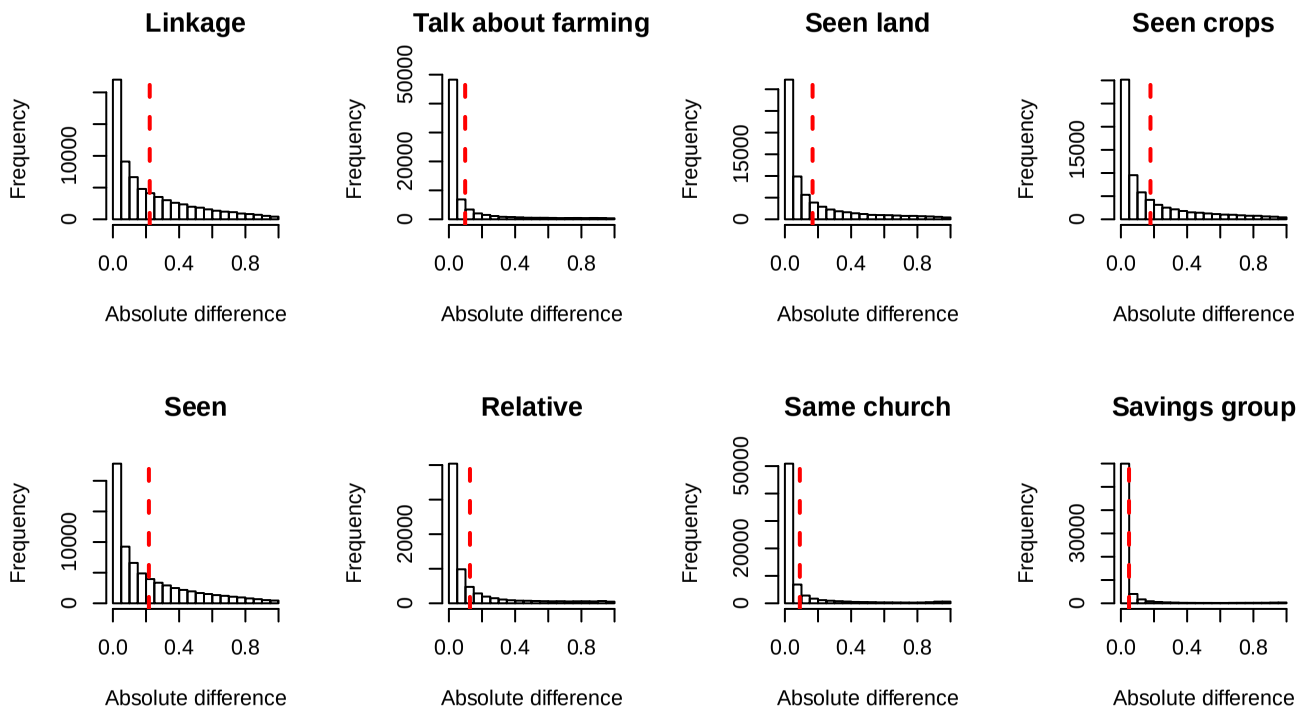


Figure 7: Crop yields on demonstration plots, compared to control plots.

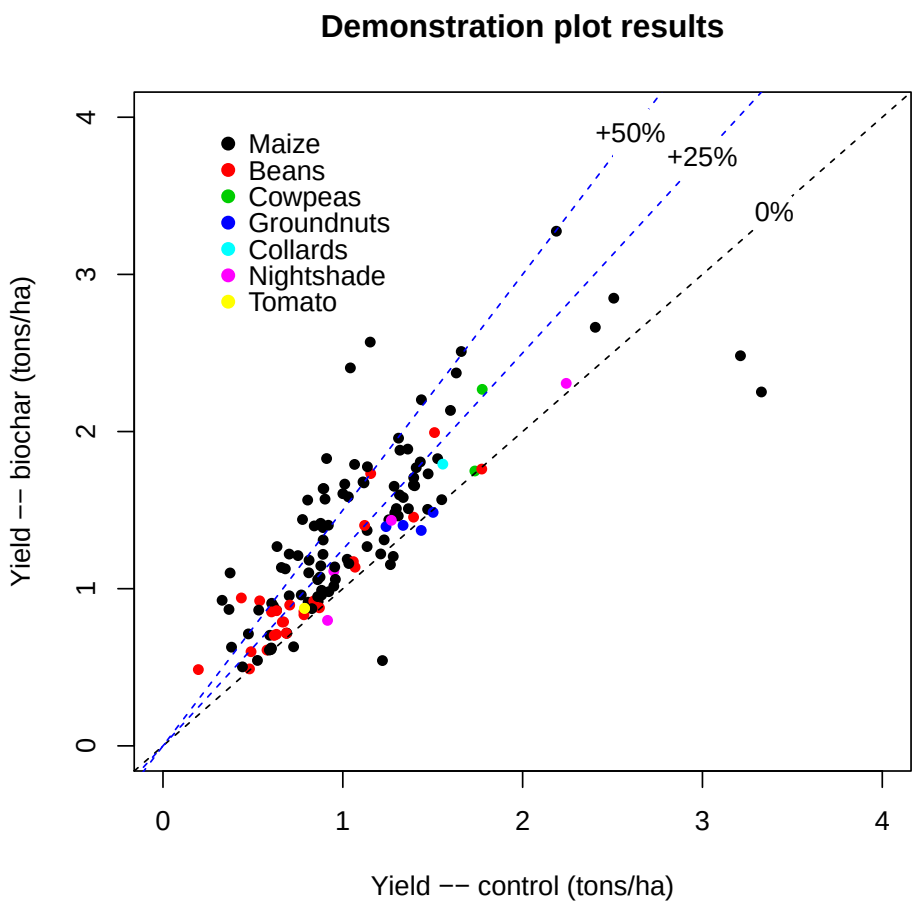


Figure 8: Utility of biochar adoption at a cost of \$125/ha (KSh850 per quarter acre plot), for a decisionmaker with a mean-standard deviation utility function of the form $U(\mu, \sigma) = \mu^{\theta} - \sigma^{\gamma}$. The mean and standard deviation of observed profits from demonstration plots are \$27 and \$140 per hectare, respectively. The bold contour line represents the combination of taste parameters for the mean and standard deviation at which the modeled decisionmaker would be indifferent to biochar adoption. Following Saha [71], $\gamma < 0$ corresponds to risk aversion, and $\theta < 1$ corresponds to declining average risk aversion (conditional on $\gamma < 0$.)

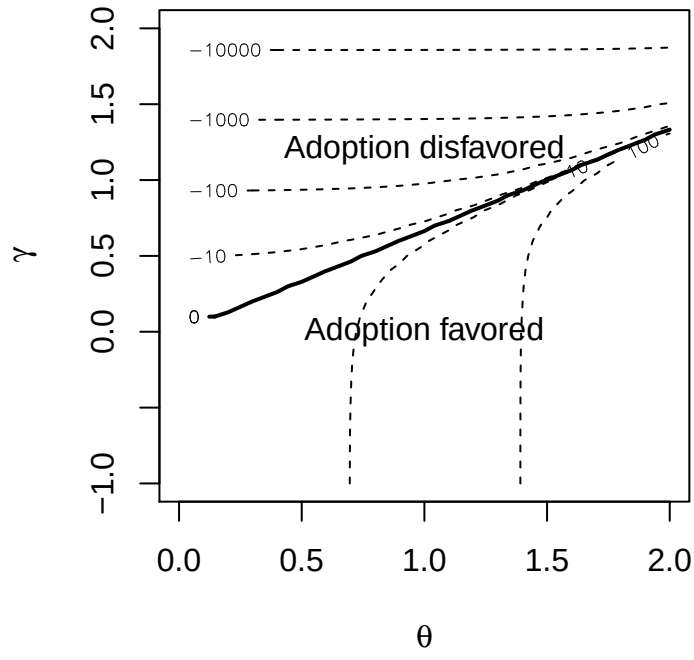


Table 6: Results of model 2. Gamma results are raw coefficients – marginal effects on the link function (log) scale.

	OLS				Gamma			
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
(Intercept)	1.37^{***}	1.70^{***}	1.58^{***}	1.56^{***}	0.32^{***}	0.56^{***}	0.47^{***}	0.46^{***}
	(0.04)	(0.09)	(0.10)	(0.10)	(0.03)	(0.06)	(0.07)	(0.07)
Control yield		-0.26^{***}	-0.30^{***}	-0.32^{***}		-0.21^{***}	-0.23^{***}	-0.25^{***}
		(0.03)	(0.03)	(0.03)		(0.02)	(0.02)	(0.02)
DAP			0.07	0.13^{**}			0.05^{*}	0.10^{**}
			(0.04)	(0.04)			(0.02)	(0.03)
CAN			0.14^{**}	0.25^{***}			0.10^{**}	0.18^{***}
			(0.05)	(0.06)			(0.03)	(0.04)
Urea			0.04	0.03			0.03	0.02
			(0.05)	(0.05)			(0.03)	(0.03)
DAP×CAN				-0.12^{**}				-0.10^{**}
				(0.05)				(0.03)
AIC	102.31	88.21	80.52	75.28	87.85	69.67	61.77	54.62
BIC	107.52	96.02	96.09	93.45	93.06	77.49	77.34	72.78
Log Likelihood	-49.16	-41.10	-34.26	-30.64	-41.93	-31.84	-24.88	-20.31
Deviance	15.65	13.32	11.58	10.76	7.65	6.27	5.41	4.93
Num. obs.	100	100	99	99	100	100	99	99

$^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$

Figure 9: Left: Likert-scale responses to the question "how were the yields on the biochar portion of the demonstration plot, compared to the portion of the demonstration plot without biochar." Right: Likert scale responses to the question "among others you know with biochar demonstration plots, how were yields on the biochar portion of their demonstration plots, compared to the portions of their demonstration plots without biochar."

Table 7: Average measured demonstration plot relative increases among social network contacts, by stated perception of the relative magnitude of the average differences, across different dimensions of social network linkage. We include both reported (sampled) networks (upper panel) and probabilistically imputed networks (lower panel).

		Very Good	Good	Same	Didn't See
	Links	25.53	28.36	31.53	28.23
Average	Links with whom farming discussed	24.45	27.95	26.90	24.05
demo plot	Links seen in past month	27.71	29.25	28.66	28.66
relative	Links seen crops in past month	26.20	27.77	32.46	26.64
increase	Links seen land in past month	25.24	26.74	28.27	28.73
among	Relatives	25.41	25.52	58.55	30.99
reported...	Fellow church members	25.64	28.02	28.13	23.70
	Fellow savings group members	26.72	34.21	80.84	30.41
	Links	27.32	28.14	30.18	28.04
Average	Links with whom farming discussed	25.92	26.35	26.14	25.63
demo plot	Links seen in past month	28.75	29.30	29.89	29.39
relative	Links seen crops in past month	27.20	27.47	29.49	27.34
increase	Links seen land in past month	26.76	26.75	28.19	27.67
among	Relatives	28.45	28.64	39.05	30.10
imputed...	Fellow church members	25.98	26.71	27.38	26.21
	Fellow savings group members	29.16	29.16	33.34	29.09

Figure 10: Upper: The distribution of measured percentage differences in yield between biochar and control portions of demonstration plots, by stated perception of the relative magnitude of the difference, for holders of demonstration plots. Lower: the distribution of weighted average measured percentage differences in yield between biochar and control portions of demonstration plots within (imputed) social networks, by stated perception of the relative magnitude of the average differences, for the full sample.

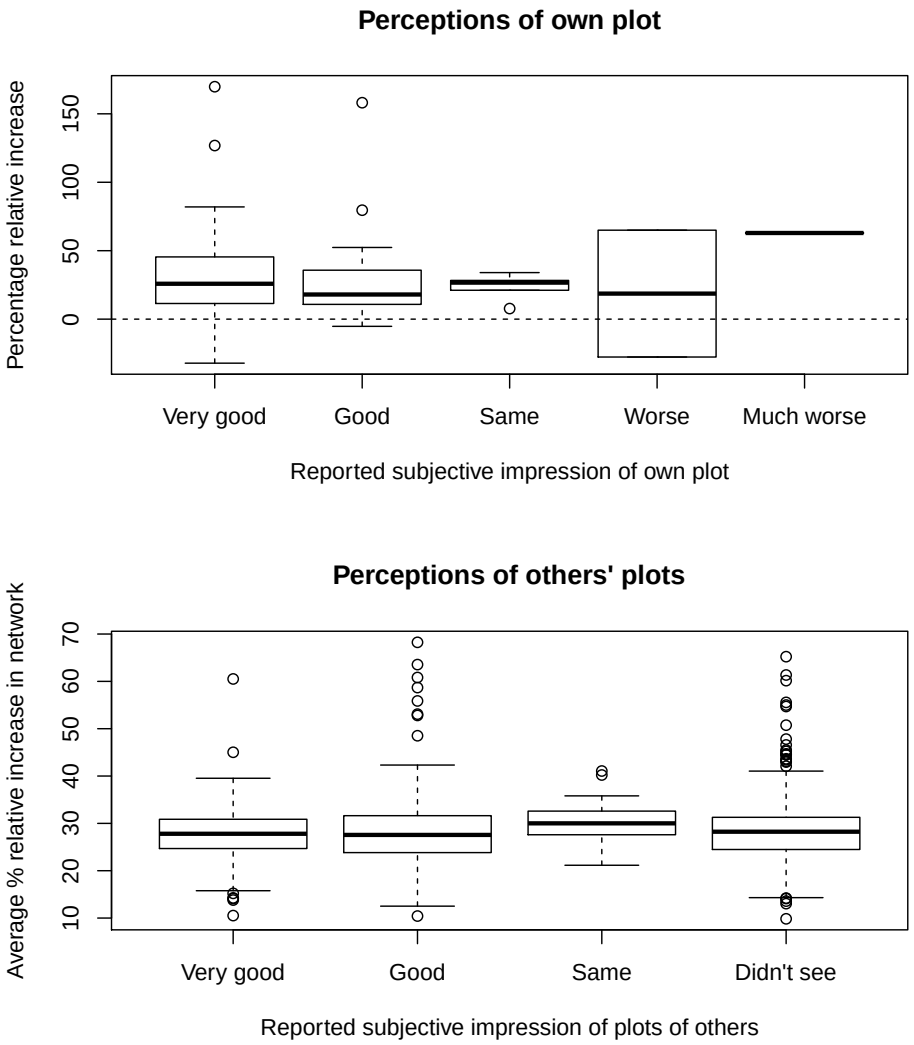


Figure 11: Logistic generalized additive model relating uptake in early 2014 to randomized prices. Price represented as a penalized linear spline, with knots at each unique price offered and smoothing parameter selection by generalized cross-validation.

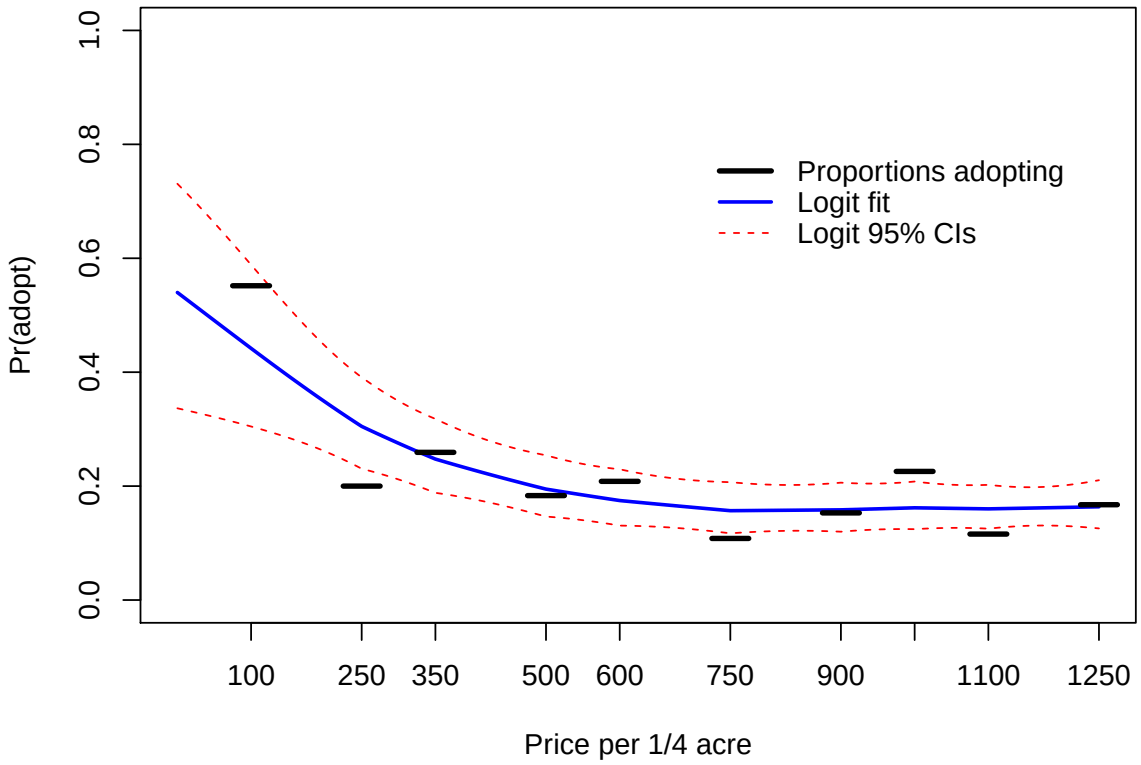


Figure 12: Logistic GAMs relating uptake in early 2014 to the share of each farmer's network adopting biochar (left) and the number of links in each farmers network (right). The right logit controls for the total number of links in each farmer's network, and the fit represents the marginal effect at the mean number of network links.

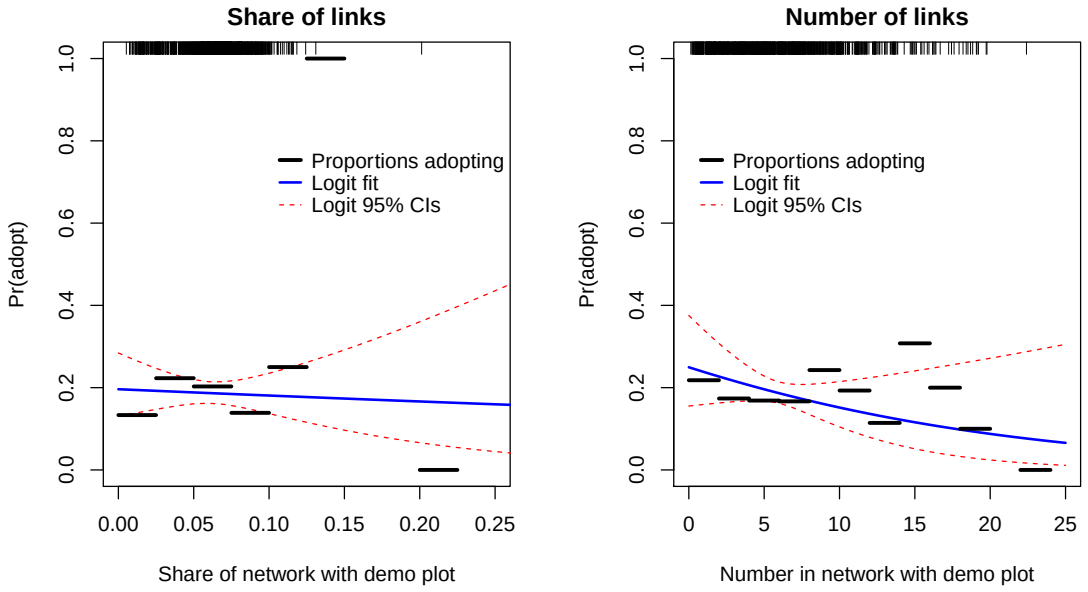
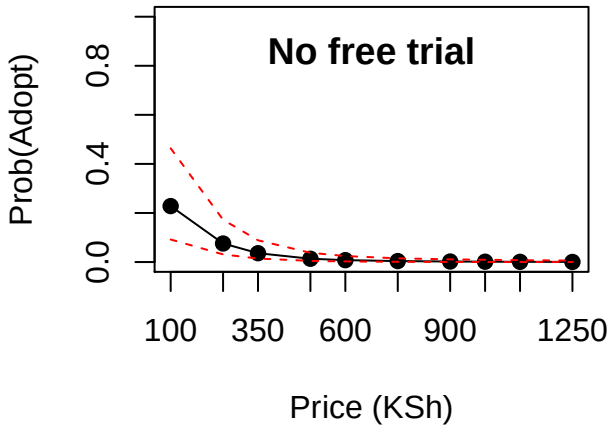


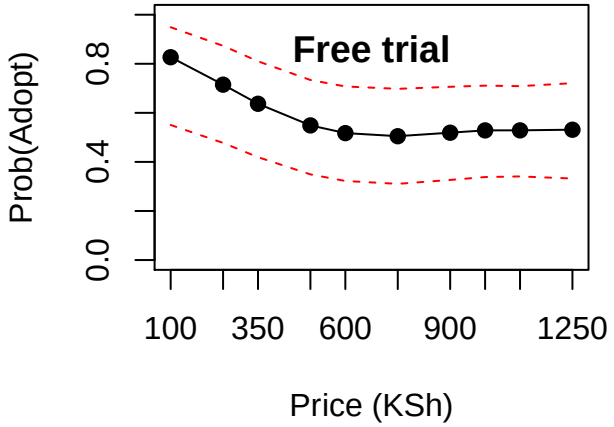
Table 8: Logistic regression coefficients and naive p-values relating biochar uptake to the shares (left) and numbers (right) of various dimensions of a social network taking up biochar, using observed ("Obsd.") and imputed ("impd") networks. None of the significant p-values are robust to a Holm-Bonferonni correction.

		Share of network			Number in network		
		$\hat{\beta}$	$se(\hat{\beta})$	$p(\lvert\hat{\beta}\rvert) > 0$	$\hat{\beta}$	$se(\hat{\beta})$	$p(\lvert\hat{\beta}\rvert) > 0$
Links	Obs.	0.42	1.35	0.76	-0.02	0.07	0.79
	Impd.	-1.00	3.77	0.79	-0.06	0.05	0.20
Talked farming	Obs.	-0.27	0.75	0.72	0.01	0.13	0.94
	Impd.	-0.76	1.90	0.69	-0.03	0.10	0.79
Seen land	Obs.	0.79	0.95	0.40	0.02	0.09	0.80
	Impd.	1.74	2.45	0.48	-0.04	0.07	0.60
Seen Crops	Obs.	0.08	0.99	0.94	-0.03	0.09	0.75
	Impd.	0.08	2.76	0.98	-0.07	0.07	0.31
Seen	Obs.	0.33	1.31	0.80	-0.04	0.07	0.54
	Impd.	-0.49	3.57	0.89	-0.08	0.05	0.11
Relatives	Obs.	0.17	0.70	0.81	-0.06	0.13	0.65
	Impd.	-0.70	2.47	0.78	-0.09	0.11	0.40
Savings Group	Obs.	1.22	0.59	0.04	0.23	0.20	0.25
	Impd.	3.60	2.07	0.08	0.17	0.18	0.34
Church	Obs.	1.24	0.53	0.02	0.24	0.15	0.11
	Impd.	5.76	2.30	0.01	0.18	0.13	0.16
Distance	Within 1km	-1.71	3.83	0.65	-0.01	0.03	0.75
	Within 2km	-3.83	5.36	0.48	0.02	0.03	0.44
EV cent. weighted	Impd.	-5.51	11.87	0.64	-0.06	0.16	0.71

Table 9: Results of model 9. Parametric logit coefficients are given on the left, marginal effects of price and free trial at the means of other covariates are given at the right, with 95% confidence intervals. "EDF" stands for effective degrees of freedom for smoothed terms. Hypothesis tests for smooth terms based on reduced-rank Wald tests [76] for joint equality to zero among all smoothed terms comprising a function.

(Intercept)	-5.81^{***}
	(0.97)
Share of network with demo	-3.84
	(8.01)
Got demo plot	1.34^{*}
	(0.56)
Gender	-0.09
	(0.31)
Income	0.00
	(0.00)
Zone: Mateka	-0.45
	(0.41)
Zone: Mukwa	0.07
	(0.42)
Zone: Nasianda	0.09
	(0.49)
Heard of Re:char	-0.17
	(0.63)
Heard of ACON	1.62^{**}
	(0.55)
Has used charcoal as fertilizer	-0.82
	(0.73)
Heard of the Rutuba	-0.32
	(0.61)
Dist. from center of zone	13.24
	(27.89)
EDF: f(Price)	2.54^{***}
	(3.19)
EDF: f(Price, Free Trial)	2.00^{***}
	(2.00)
Log Likelihood	-185.10
Deviance	370.20
Deviance explained	0.55
Num. obs.	863





$^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$

Table 10: Comparison of different specifications of model 9; a linear probability model, a parametric logistic model, a gaussian additive model, and a binomial GAM (replicated from table 9).

	OLS Model 1	Logit Model 2	Gaussian GAM Model 3	Binomial GAM Model 4
(Intercept)	0.28^{***}	0.36	0.00	-5.81^{***}
	(0.07)	(0.94)	(0.05)	(0.97)
Price (100KSh)	-0.07^{***}	-1.29^{***}		
	(0.02)	(0.35)		
Price^2	$3.7 \times 10^{-3***}$	0.06^{*}		
	(0.00)	(0.03)		
Free Trial	0.59^{***}	1.24		
	(0.11)	(1.11)		
Share of network with demo	−0.10	−4.10	−0.15	−3.83
	(0.59)	(8.03)	(0.59)	(8.01)
Gender	0.00	−0.10	0.00	−0.09
	(0.02)	(0.32)	(0.02)	(0.31)
Income	0.00	0.00	0.00	0.00
	(0.00)	(0.00)	(0.00)	(0.00)
Got demo plot	0.10^{*}	1.34^{*}	0.10^{*}	1.34^{*}
	(0.04)	(0.57)	(0.04)	(0.56)
Zone: Mateka	−0.05	−0.43	−0.04	−0.45
	(0.03)	(0.41)	(0.03)	(0.41)
Zone: Mukwa	−0.01	0.09	0.00	0.07
	(0.03)	(0.42)	(0.03)	(0.42)
Zone: Nasianda	0.00	0.06	0.00	0.09
	(0.04)	(0.49)	(0.04)	(0.49)
Heard of Re:char	−0.02	−0.10	−0.02	−0.16
	(0.05)	(0.64)	(0.05)	(0.63)
Heard of ACON	0.10^{**}	1.66^{**}	0.10^{**}	1.62^{**}
	(0.03)	(0.57)	(0.03)	(0.55)
Has used charcoal as fertilizer	−0.04	−0.82	−0.04	−0.82
	(0.05)	(0.73)	(0.04)	(0.73)
Heard of the Rutuba	−0.04	−0.29	−0.04	−0.32
	(0.04)	(0.61)	(0.04)	(0.61)
Dist. from Center of Zone	1.18	13.33	1.02	13.33
	(2.06)	(28.06)	(2.05)	(27.88)
Price × Free trial	0.01	0.97^{*}		
	(0.03)	(0.42)		
Price^2 × Free trial	0.00	−0.04		
	(0.00)	(0.03)		
EDF: f(Price)			4.83^{***}	2.54^{***}
			(5.86)	(3.19)
EDF: f(Price, Free Trial)			2.00^{***}	2.00^{***}
			(2.00)	(2.00)
R^2	0.52		0.51	
Num. obs.	863	863	863	863
AIC	231.85	406.16	225.54	405.33
BIC	322.29	491.85	324.68	488.85
Log Likelihood		-185.08	-91.94	-185.12
Deviance		370.16	62.38	370.25
Dispersion			0.07	1.00
Num. smooth terms			2	2

$^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$

Figure 13: Comparisons of several specifications of model 9 – OLS, additive gaussian, parametric logit, and additive gaussian. Marginal effects at means of non-plotted covariates given for gaussian models (a) and logit model (b). Comparison of predictons for different models given in (c). Differences in marginal effects at means of covariates given in (d) and (e) by free trial status.

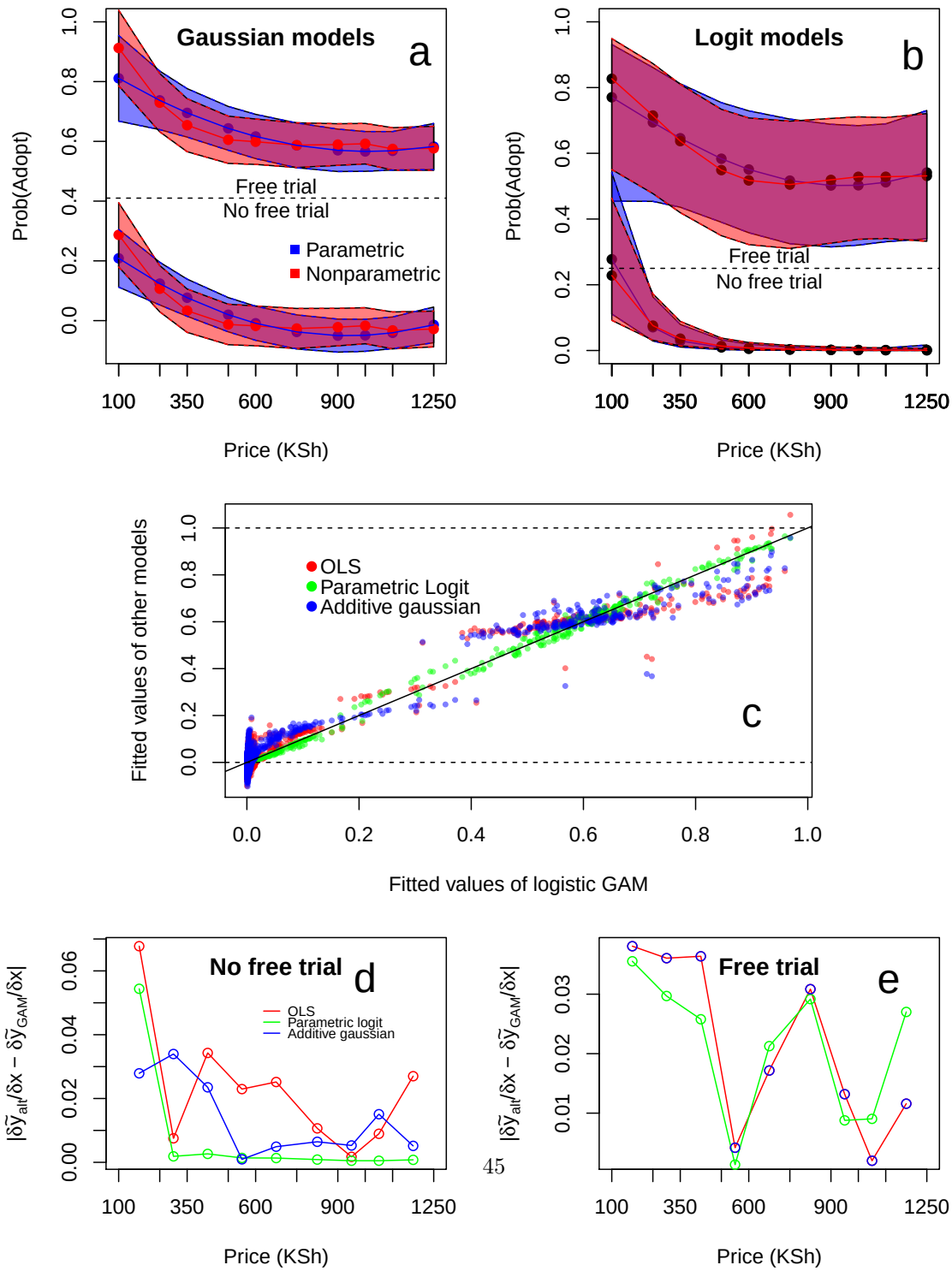


Figure 14: Non-parametric estimates (marginal effects at means of non-pictured covariates) from model 4. All terms significant at $p < .05$ or less. Hypothesis tests for smooth terms based on reduced-rank Wald tests [76] for joint equality to zero among all smoothed terms comprising a function. The lower right figure is a contour plot, where contour height represents the conditional expectation of the probability of adoption for a given observed mean or standard deviation.

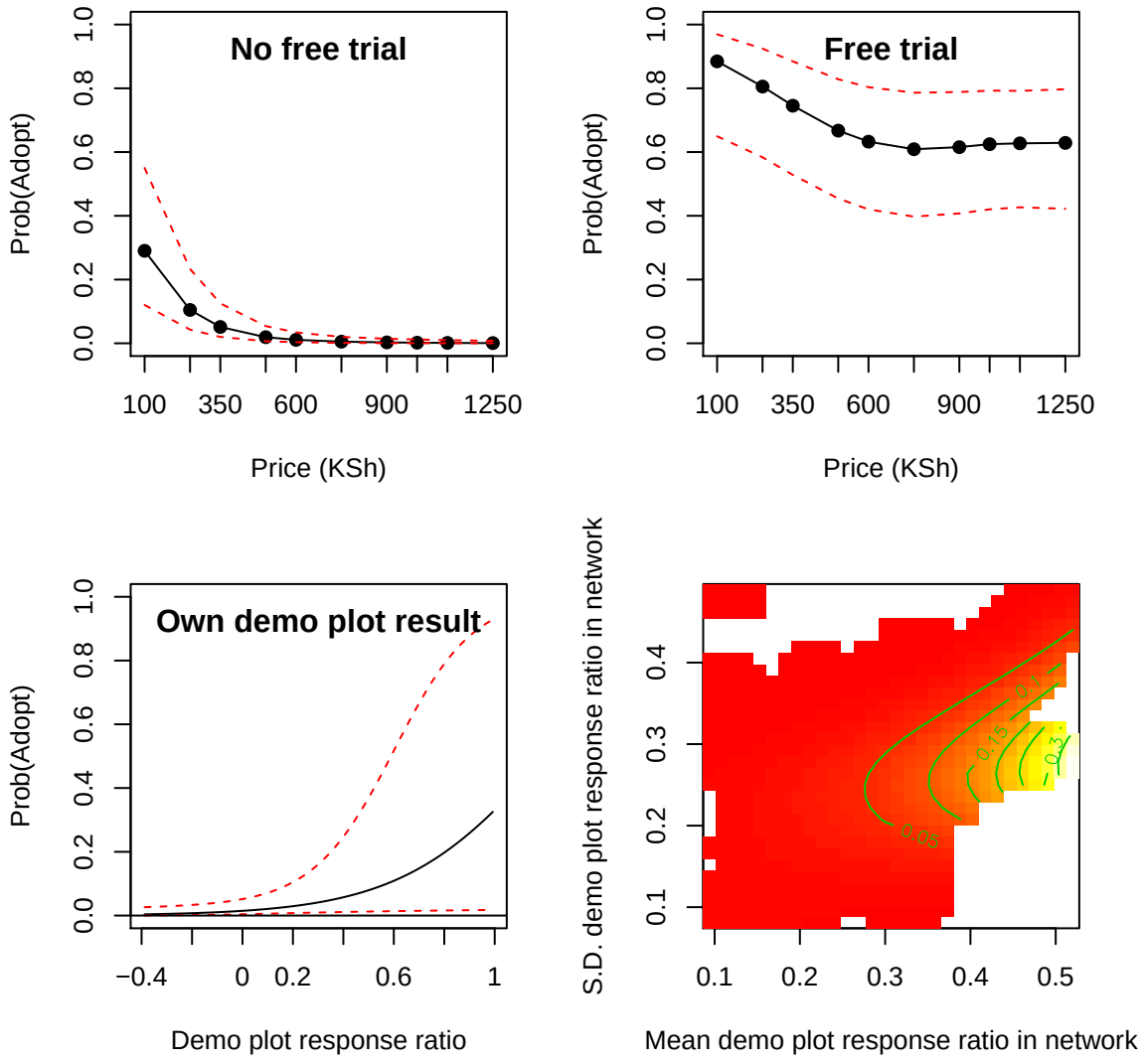
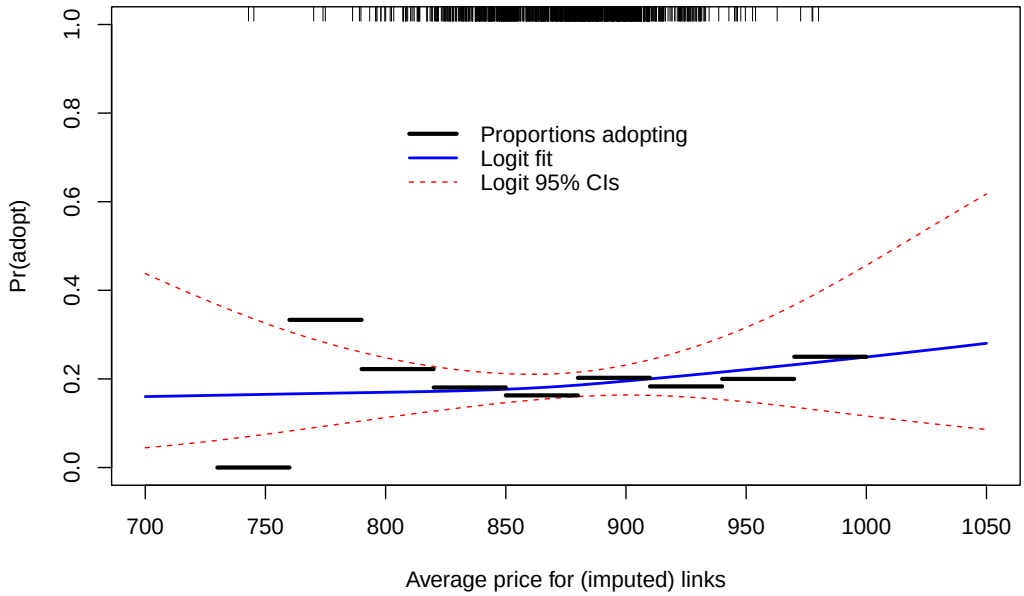


Figure 15: Univariate nonparametric logit fits relating the average price for (partially-imputed) network links (left) and the proportion of the network having a free trial (right).



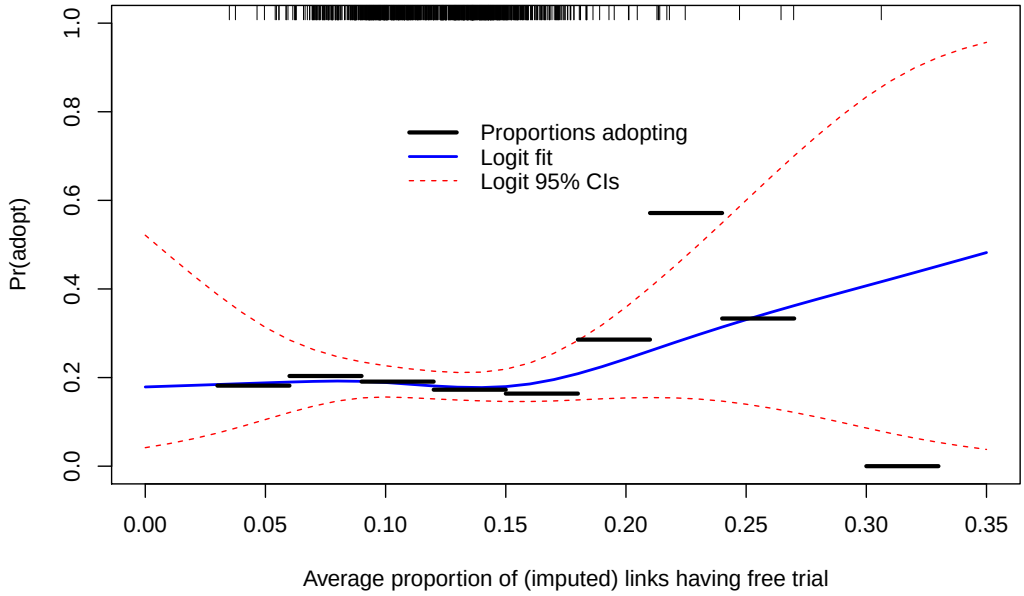


Figure 16: Maize yields on biochar plots as compared to non-biochar plots on fields of farmers adopting in early 2014. Left: raw data. Right: adjusted data, based on estimates from model 5. Univariate fits relating biochar yields to control yields are log-linked gamma GAMs.

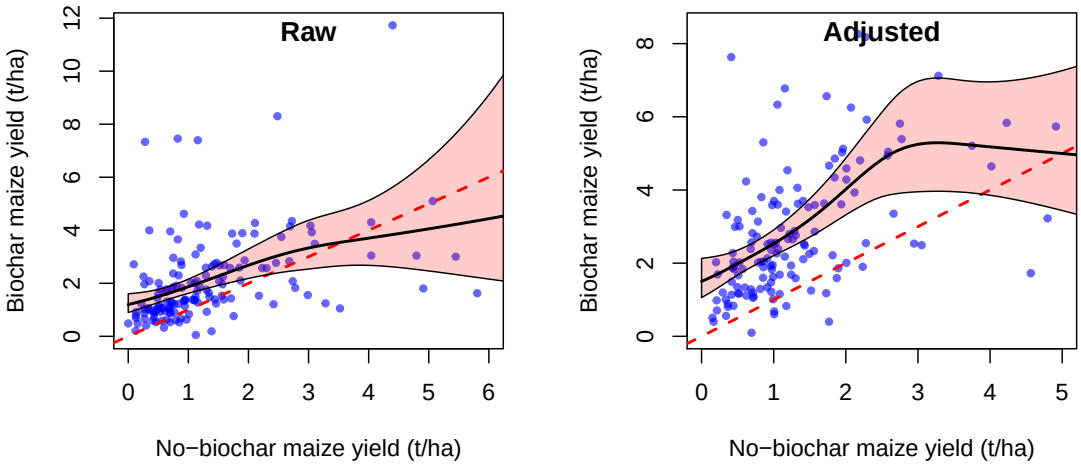


Figure 17: Left: impressions of the difference in yield between portions of farms with biochar, and portions without. Right: distributions of adjusted yield, by stated impression of impact.

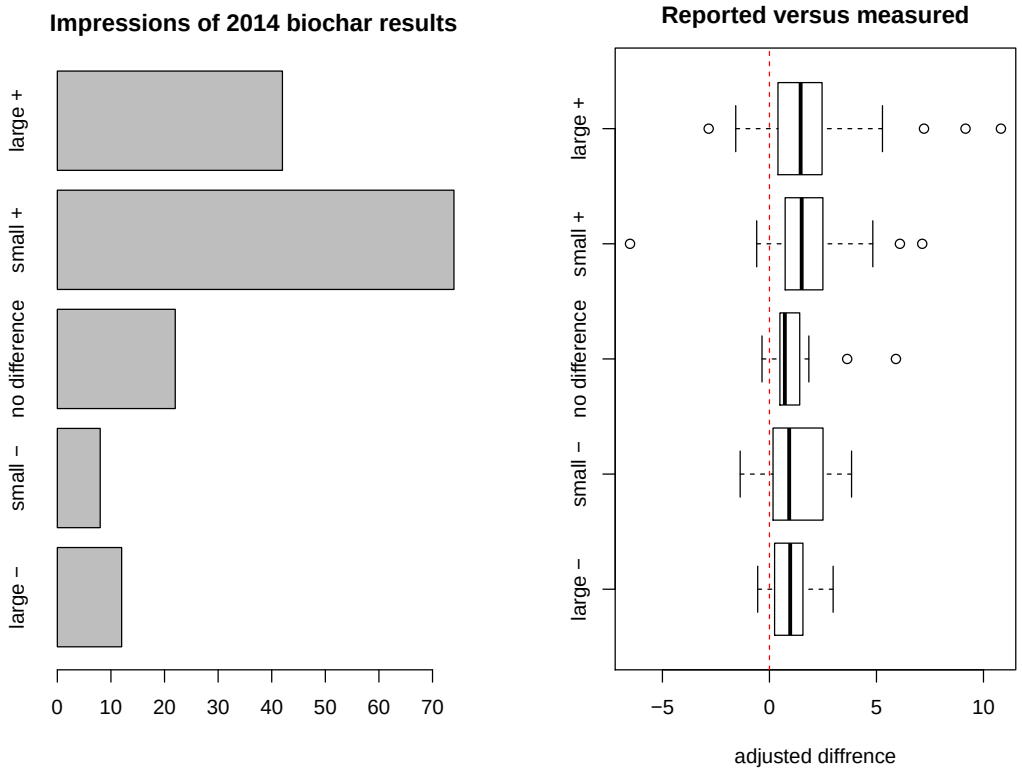


Table 11: Regression results from model 6; estimates of biochar adoption impact based on self-reported data.

	Dependent variable:							
	Maize yields (90kg bags/acre)							
	Cross-sectional					*Panel*		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Adopted Biochar	−0.304	−0.938**	−0.179	−0.717	−0.521	−0.339	−0.339	−0.176
	(0.326)	(0.373)	(0.462)	(0.562)	(0.510)	(0.313)	(0.313)	(0.287)
DAP fertilizer					0.028***			0.029***
					(0.007)			(0.005)
CAN fertilizer					0.047***			0.032***
					(0.008)			(0.004)
Urea fertilizer					0.024***			0.020***
					(0.008)			(0.006)
Acres under maize					−3.287***			−2.563***
					(0.311)			(0.208)
Constant	6.568***	60.288	6.545***	288.421	225.257			
	(0.135)	(493.732)	(0.155)	(488.757)	(441.718)			
Covariates	No	Yes	No	Yes	Yes	No	No	No
IV	No	No	Yes	Yes	Yes	No	Yes	Yes
Observations	865	860	792	792	792	5,821	5,821	5,808
R^2	0.001	0.132	0.001	0.099	0.268	0.567	0.567	0.619
Adjusted R^2	−0.0002	0.088	−0.0004	0.066	0.237	0.482	0.482	0.543

Note: $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

1¿ texreg(list(mfs5))

Figure 18: Upper panel: Reported versus measured yields and land under maize for the portion of the sample adopting biochar in early 2014. Lower panel: range of reported maize harvests (reported quantities of maize divided by reported land are under maize) by individual respondents who were surveyed multiple times, for the late-2013 and early 2014 harvest seasons.

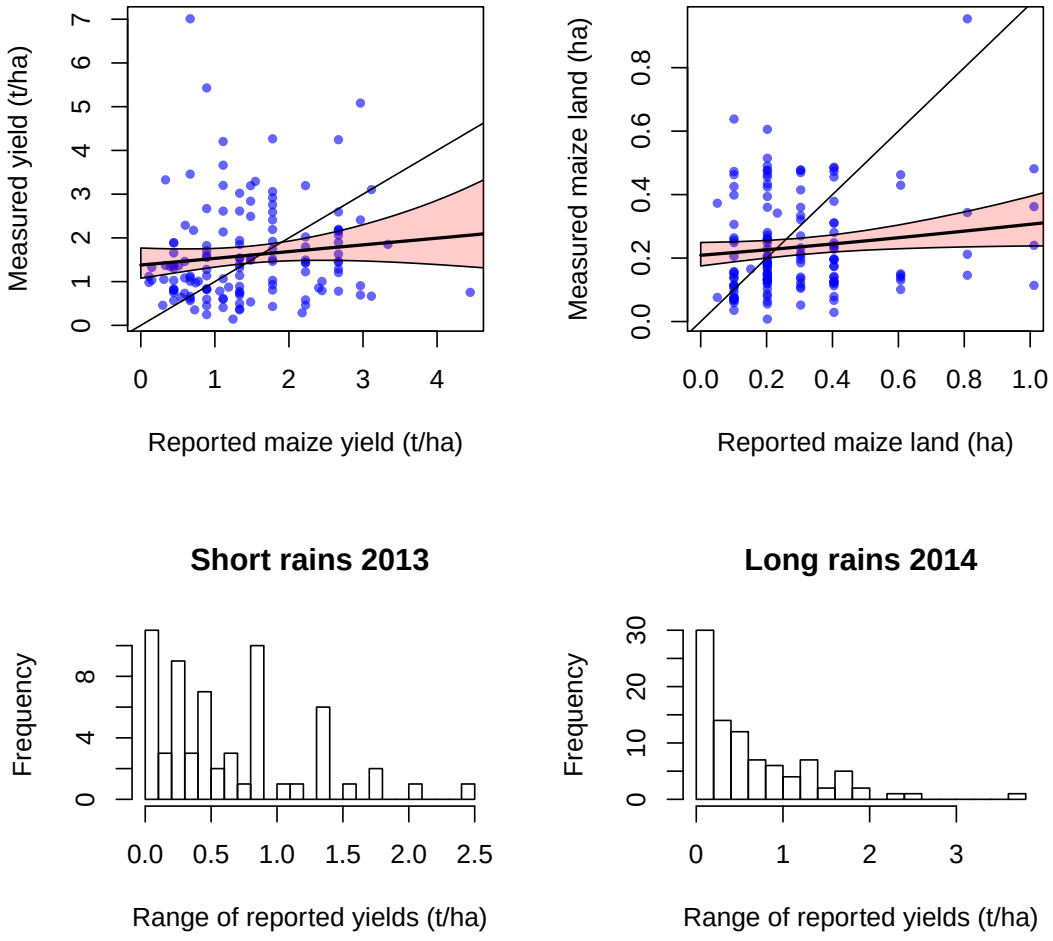


Table 12: Results of a logistic GAM relating free trial repayment (binary) to whether or not the respondent had already planted, their reported subjective impression of the results of the biochar that they got, the amount that they had to repay, their reported expected expenditure for the 2014 short rains season, the measured difference between biochar yields and control yields, and their reported income in the previous month. Nonparametric smooth function estimates given in figure 19.

	Model 1
(Intercept)	-4.82^{**}
	(1.59)
Not yet planted	1.76
	(0.91)
Partially planted	0.53
	(0.82)
Impression: "Very good"	0.46
	(1.06)
Impression: "Good"	-1.03
	(1.10)
Impression: "Bad"	0.25
	(1.74)
Impression: "Very bad"	0.64
	(1.21)
EDF: s(to.repay)	1.00^{***}
	(1.00)
EDF: s(sr14willspend)	2.26
	(2.74)
EDF: s(rawdiff)	1.00
	(1.00)
EDF: s(inc)	1.92^{*}
	(2.37)
Deviance explained	0.32
Dispersion	1.00
R^2	0.21
Num. obs.	132
Num. smooth terms	4

$^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$

Figure 19: Nonparametric estimates from the model reported in table 12.

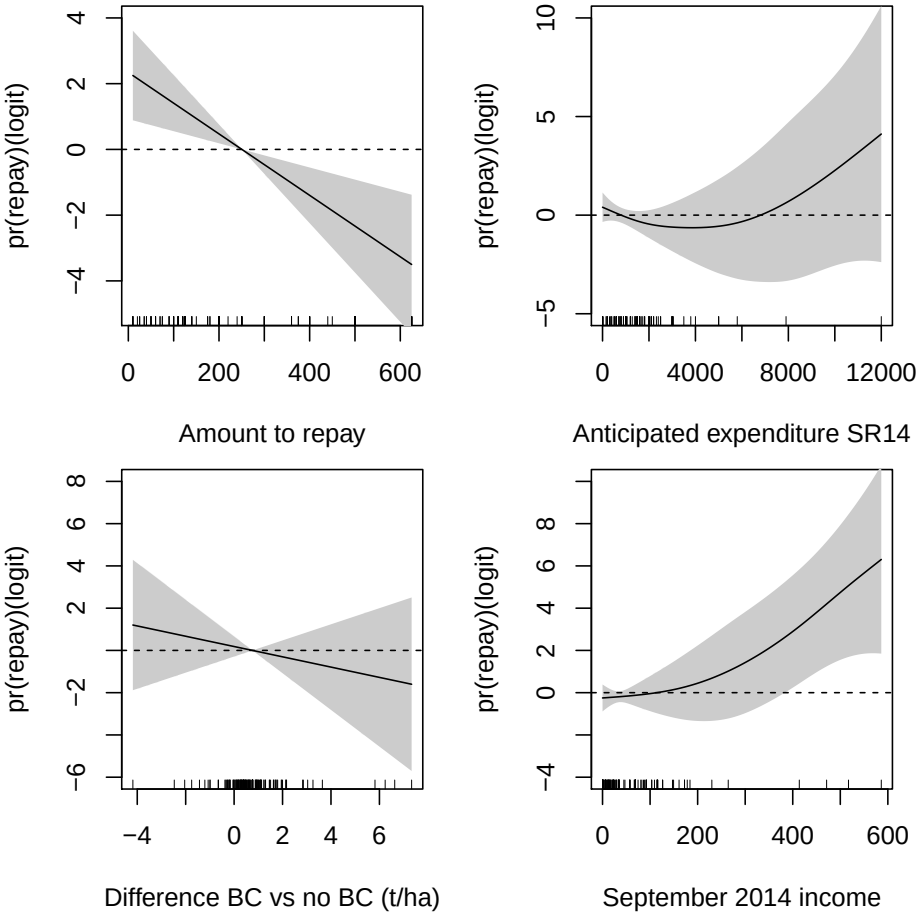
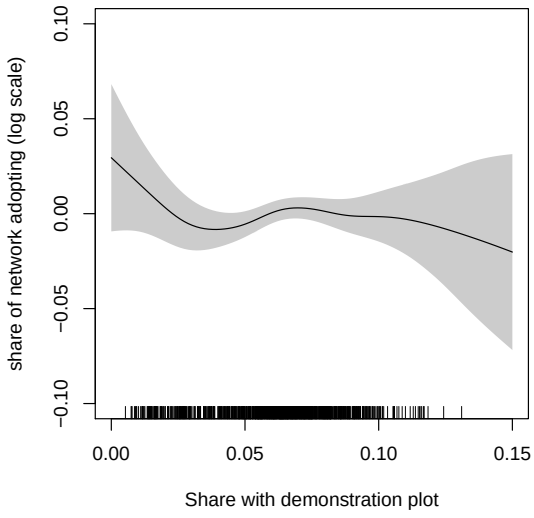


Table 13: Results of a model predicting the share of network contacts adoption biochar with the network analogs of the treatments that were randomized in early 2014. "EDF" stands for effective degrees of freedom, and summarizes the post-penalization dimensions of a smooth term. Numbers in paranetheses below reported EDFs give the statistic associated with Wood's [76] reduced-rank Wald test for smoothed components of GAMs. Both figures give marginal effects of variables on the logit scale. The right figure is a contour plot, where the contour heights represent marginal effects on the logit scale.

	Model 1
(Intercept)	-1.97^{***}
	(0.01)
EDF: f(Share with demo plots)	4.41
	(5.45)
EDF: f(share with free trials, average price)	37.32^{***}
	(44.11)
Deviance	2.81
Deviance explained	0.96
R^2	0.96
Num. obs.	947

$^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$



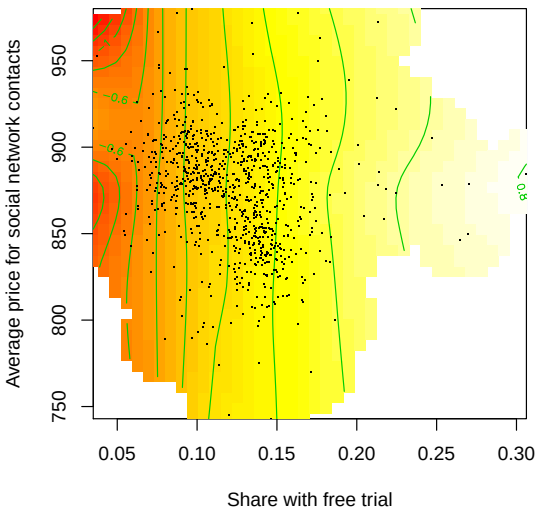


Table 14: Results of model 7 for four specifications with different interaction structures. "EDF" stands for effective degrees of freedom, and summarizes the post-penalization dimensions of a smooth term. Numbers in paranetheses below reported EDFs give the statistic associated with Wood's [76] reduced-rank Wald test for smoothed components of GAMs. Marginal effects of terms significant at $p < 0.1$ given in figure 21. In addition to the terms given below, all models control for income, zone dummies, gender of household agricultural decisionmaker, distance from the center of the zone, whether the respondent had ever used charcoal as fertilizer, and whether the respondent had heard of ACON, Re:char, or the Rutuba. In addition, all models control for smooth functions of the first stage models for having gotten biochar in early 2014, and the network share of the respondent that got biochar in early 2014. Significance tests and confidence intervals all based on a variance-covariance matrix calculated using Marra & Radice's 2SGAM algorithm [68].

	Model 1	Model 2	Model 3	Model 4
(Intercept)	-4.23^{***}	-4.58^{***}	-4.58^{***}	-4.57^{***}
	(0.52)	(0.60)	(0.61)	(0.61)
Had demo plot	-1.06	-1.03	-1.06	-1.08
	(0.63)	(0.62)	(0.62)	(0.66)
Had BC in early 2014	1.20	1.50	1.26	1.12
	(0.98)	(0.91)	(0.95)	(0.97)
EDF: f(Share network with demo plot)	1.00	1.00	1.00	1.00
	(1.00)	(1.00)	(1.00)	(1.00)
EDF: f(Share network with BC early 2014)	2.47	2.62	3.26^{*}	3.22
	(3.07)	(3.26)	(4.02)	(3.96)
EDF: f(BC price)	1.84^{***}	1.77^{***}	1.97^{***}	2.03^{***}
	(2.27)	(2.18)	(2.41)	(2.48)
EDF: f(Amount to repay)	2.04	1.00	1.00	1.00
	(2.48)	(1.00)	(1.00)	(1.00)
EDF: f(Amt. repay, price)		2.51	2.28	2.33
		(3.06)	(2.76)	(2.83)
EDF: f(Demo plot share, BC14 share)			5.75	6.21
			(8.23)	(8.85)
EDF: f(BC14 share)$\times$ BC14				1.00
				(1.00)
EDF: f(Demo plot share, BC14 share) $\times$ BC14				1.00
				(1.00)
AIC	460.75	460.00	459.10	463.45
BIC	619.63	628.43	672.14	694.58
Log Likelihood	-196.52	-194.10	-184.14	-182.47
Deviance	393.03	388.21	368.29	364.93
Deviance explained	0.28	0.29	0.33	0.33
Num. obs.	806	806	806	806
Num. smooth terms	9	10	11	13

$^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$

Figure 20: Comparison of two-stage generalized additive model (2SGAM) (logit) specification of model 7 with two-stage least squares specification. Upper panels give 2SLS marginal effects of the share of the network with biochar, and price, with 95% confidence intervals. Lower panels give differences in marginal effects between 2SGAM and 2SLS specifications, per 1% change in the share of the network with biochar (left) and per 50KSh increment in the price of biochar (right), for different points in the distribution of price (left) and share of network with biochar (right).

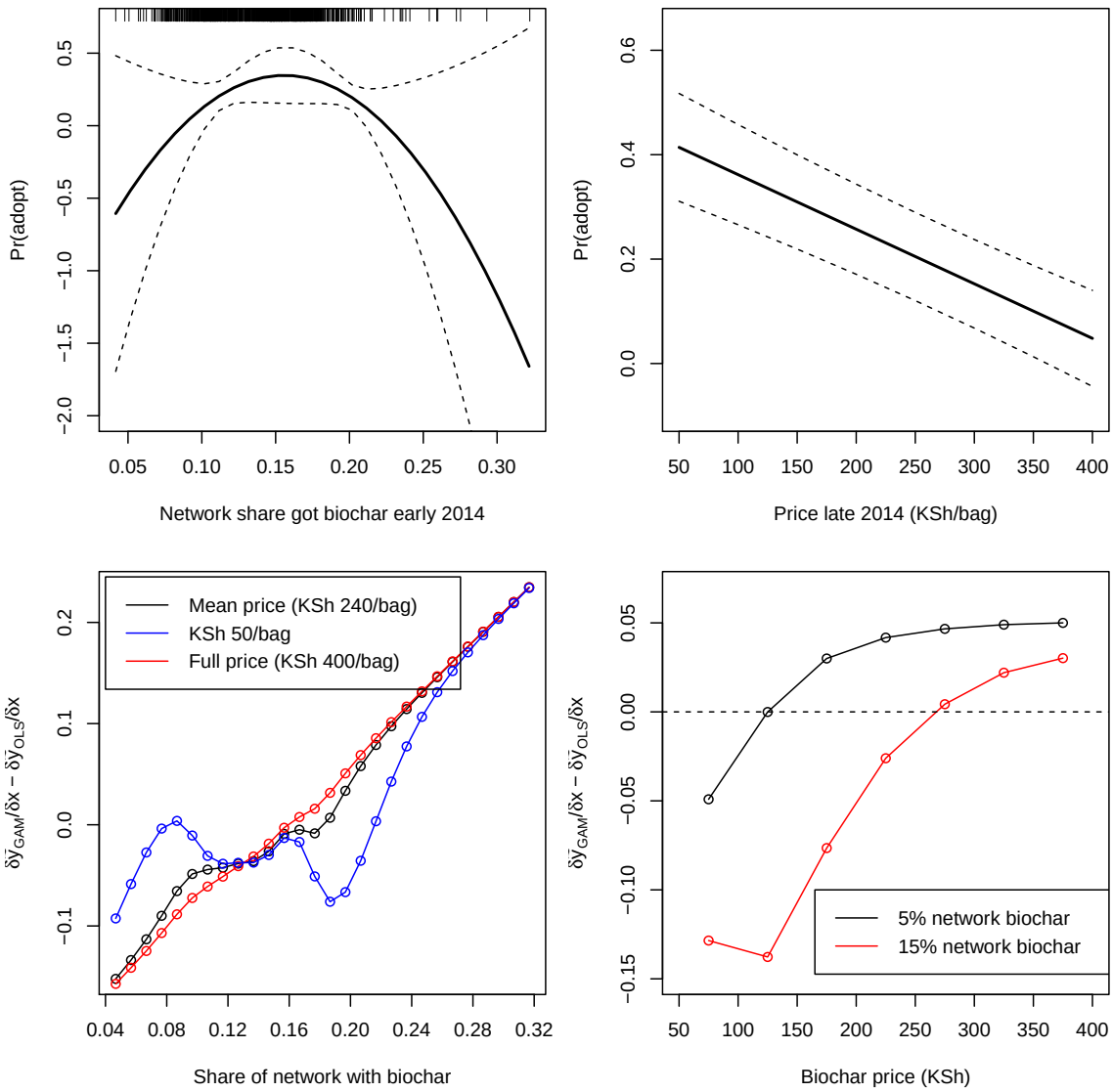


Table 15: Results of model 7 respecified with the number of bags as the dependent variable, and modeled as a poisson GAM with a logarithmic link. "EDF" stands for effective degrees of freedom, and summarizes the post-penalization dimensions of a smooth term. Numbers in paranetheses below reported EDFs give the statistic associated with Wood's [76] reduced-rank Wald test for smoothed components of GAMs. Marginal effects of terms significant at $p < 0.1$ given in the lower panel of figure 21. In addition to the terms given below, all models control for income, zone dummies, gender of household agricultural decisionmaker, distance from the center of the zone, whether the respondent had ever used charcoal as fertilizer, and whether the respondent had heard of ACON, Re:char, or the Rutuba. In addition, all models control for smooth functions of the first stage models for having gotten biochar in early 2014, and the network share of the respondent that got biochar in early 2014. Significance tests and confidence intervals all based on a variance-covariance matrix calculated using Marra & Radice's 2SGAM algorithm [68].

	Model 1	Model 2	Model 3	Model 4
(Intercept)	-4.20^{***}	-4.51^{***}	-4.45^{***}	-4.66^{***}
	(0.43)	(0.53)	(0.52)	(0.54)
Had demo plot	-1.34^{**}	-1.28^{*}	-1.21^{*}	-1.22^{*}
	(0.50)	(0.51)	(0.52)	(0.52)
Had BC in early 2014	0.95	0.94	1.07	0.97
	(0.82)	(0.89)	(0.82)	(0.83)
EDF: f(Share network with demo plot)	1.00	1.00	1.00	1.00
	(1.00)	(1.00)	(1.00)	(1.00)
EDF: f(Share network with BC early 2014)	2.40	2.50	2.56	2.48
	(2.96)	(3.09)	(3.15)	(3.06)
EDF: f(BC price)	2.56^{***}	2.21^{***}	2.11^{***}	1.29^{***}
	(3.07)	(2.65)	(2.53)	(1.46)
EDF: f(Amount to repay)	2.04^{*}	1.00	1.09	1.47
	(2.46)	(1.00)	(1.13)	(1.73)
EDF: f(Amt. repay, price)		3.24	3.66	3.14
		(4.40)	(4.93)	(3.92)
EDF: f(Demo plot share, BC14 share))			1.73	1.96
			(2.11)	(2.39)
EDF: f(BC14 share)$\times$ BC				1.00
				(1.00)
EDF: f(Demo plot share, BC14 share) $\times$ BC14				1.00
				(1.00)
AIC	664.62	666.74	670.45	670.58
BIC	860.40	874.93	873.46	894.92
Log Likelihood	-290.58	-289.00	-291.96	-287.48
Deviance	376.32	373.14	379.06	370.11
Deviance explained	0.49	0.50	0.49	0.50
Dispersion	1.00	1.00	1.00	1.00
R^2	0.45	0.45	0.45	0.45
GCV score	325.37	321.93	321.03	318.31
Num. obs.	806	806	806	806
Num. smooth terms	9	10	11	13

$^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$

Figure 21: Marginal effects of terms significant at $p < 0.1$ from model 3 given in table 14, at the mean of non-plotted covariates. The left term (share of the respondent's network having gotten biochar in early 2014) is significant at $p = 0.58$, and the right term (biochar price) is significant at $p < 0.001$. The lower panel reports marginal effects of an equivalent model (reported in table 15) respecified with the dependent variable being number of bags bought, modeled as a poisson.

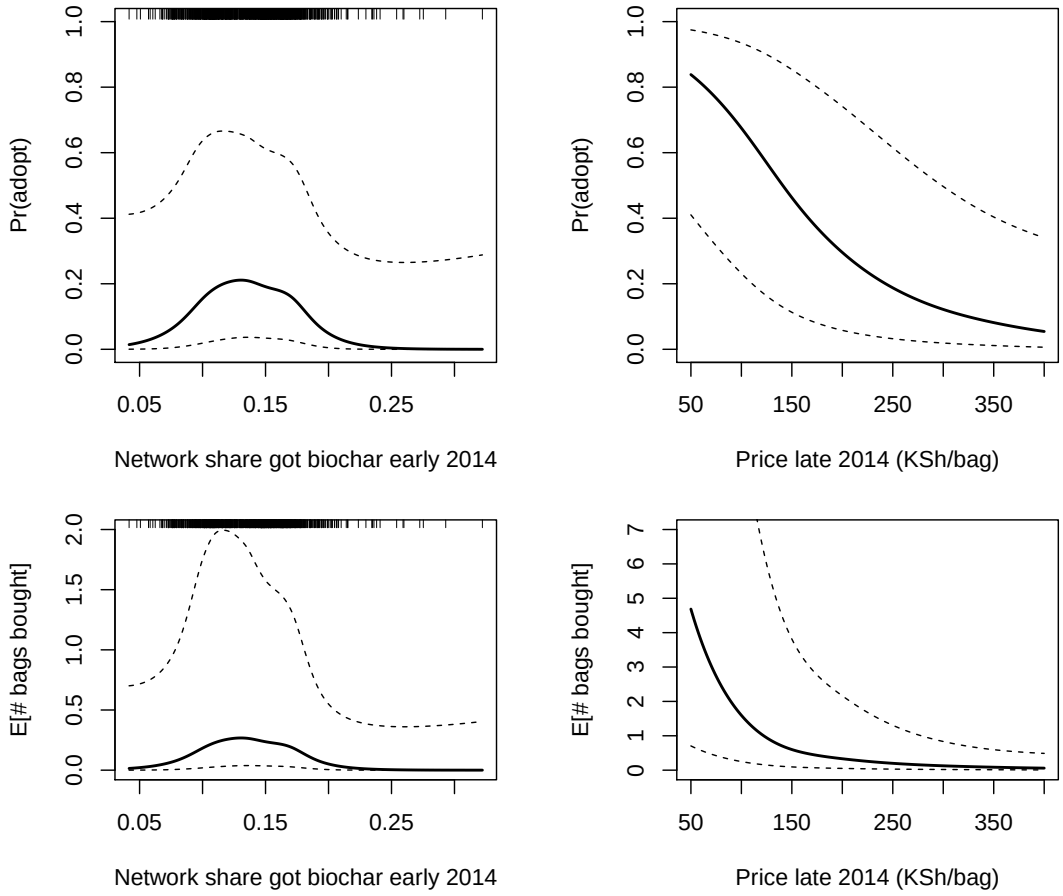
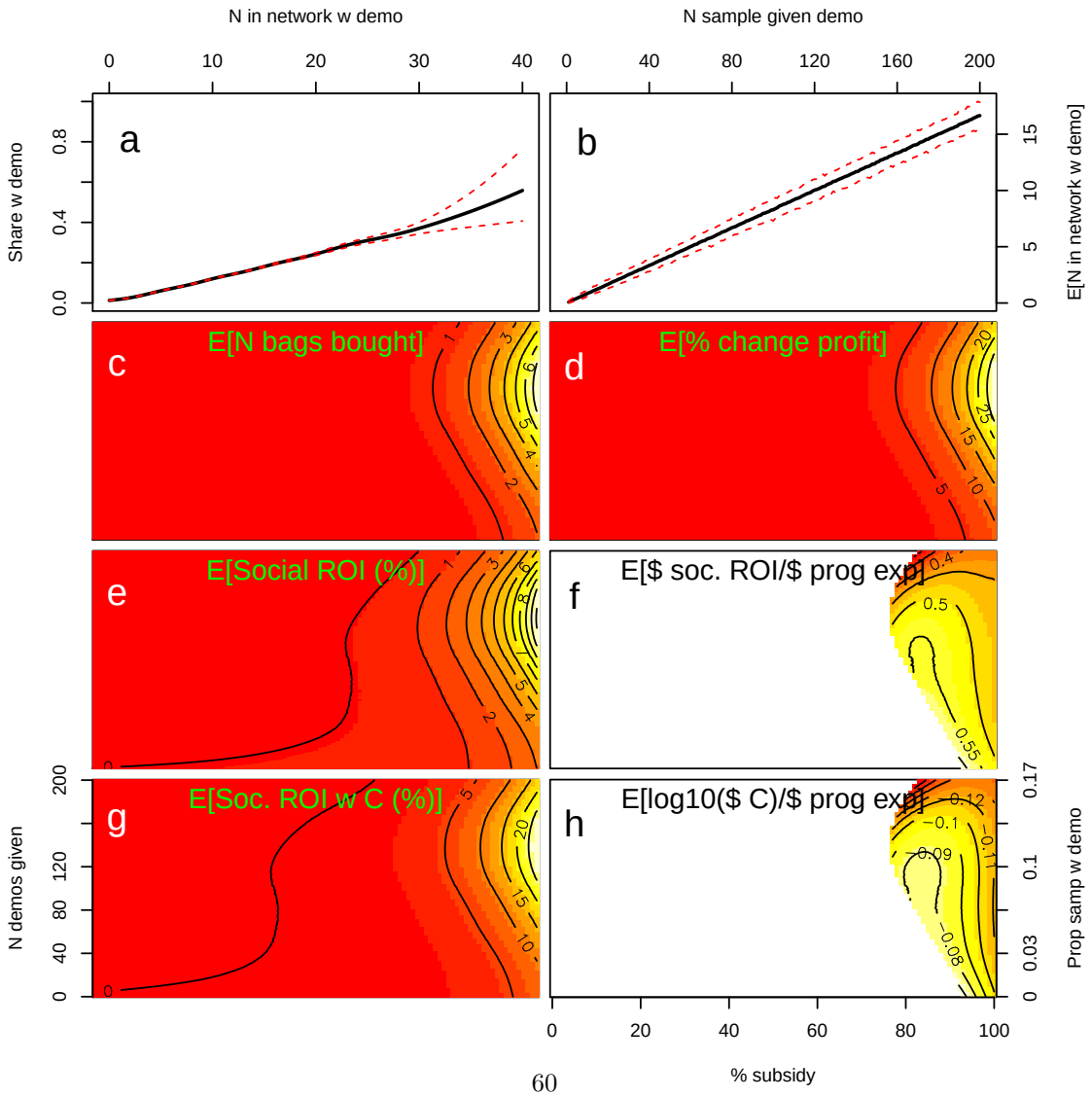


Figure 22: Prospective estimates of the welfare and social implications of direct subsidies and provision of demonstration plots for promoting biochar. (a) gives the conditional expectation of an individual's network share with a demonstration plot given the number of linked individuals in that network with demonstration plots (at the mean of total network links). (b) gives the expectation of the number of links in an average farmer's network, conditional on the number of farmers in the sample given biochar demonstration plots. (c-h) share x and y-axes, the percentage subsidy applied to a bag of biochar, and the number of demonstrations given – which equivalently is the proportion of the sample given a demonstration plot. (c) gives the expectation of the number of bags of biochar bought by an average farmer. (d) gives the expected change in profit for an individual farmer. (e) gives percentage social return on investment in subsidies. (f) gives the social ROI per dollar of program expenditure. (g) is identical to (e), but accounts for CO_2e valued at \$100/ton. (h) gives the base-10 log of sequestered carbon value per dollar program expenditure.



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Scaling Biochar: Dissemination plan and outreach strategy

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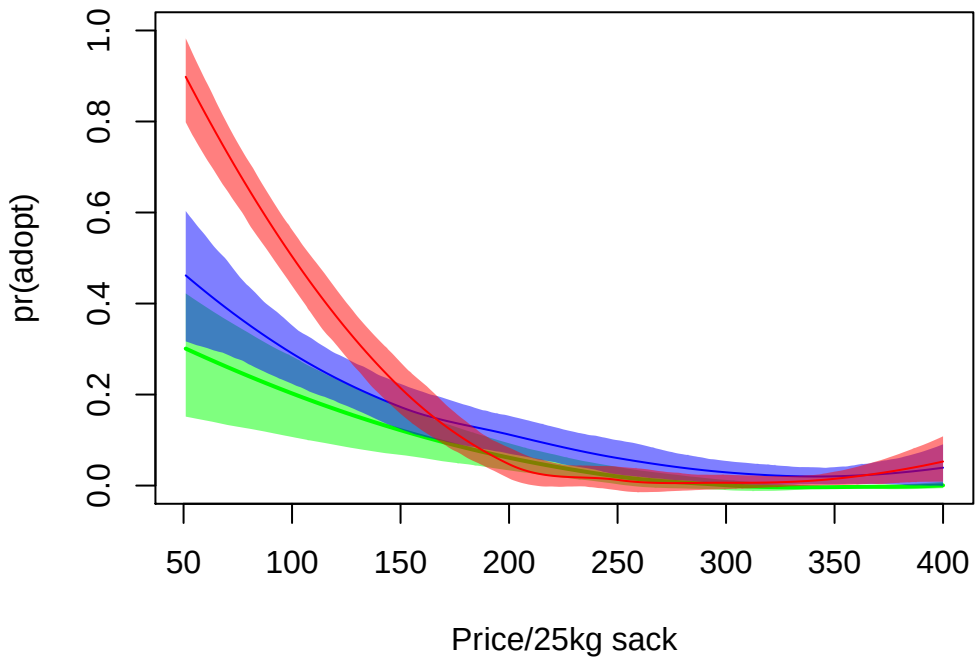
1 Summary of findings

This project – a randomized controlled trial focused on biochar impact and adoption among smallholder farmers in Western Kenya – has been a qualified success. Its central objectives were to determine biochar's potential to improve livelihoods of smallholder farmers, and to pilot approaches to the dissemination of novel agricultural technologies among smallholder farmers. We found that biochar has substantial potential to improve crop yields – yield increases ranged from 37-50% – both directly and through improved response to inorganic fertilizer. These findings, which are larger than much of what has been documented in the agronomic literature, suggest that biochar has potential to stimulate the sustainable intensification of agriculture in the region. Yield increases were particularly large where baseline yields were low, suggesting biochar has potential both to contribute to fertility restoration in degraded soils, but also to have a pro-poor impact distribution. However, uptake by farmers was quite low, in spite of these encouraging agronomic findings. In the first season in which we offered biochar for sale, only 2.6% of our sample purchased it. This proportion grew to 10% in the second season. Where they occurred, biochar sales tended to be contingent on heavy subsidies – demand for biochar at prices consistent with sustainable provision of it by a profit-making business does not appear to exist at present. And while total biochar demand has been growing in our sample over the course of the project, willingness-to-pay at prices consistent with its production remains flat – demand has only increased consistently in very lowest price ranges (figure 1).

While biochar does not appear to be poised for private-sector-led takeoff, it may be a strong candidate for public-sector intervention and/or development assistance in certain contexts. First, biochar provides beneficial environmental externalities. While very high carbon prices would be required for sequestration to cover the cost of production and dissemination, more-modest valuation of the carbon sequestered could improve the attractiveness of investments in biochar dissemination projects substantially. Second, many of the farmers who stand to gain the most from biochar may not be in a position to avail themselves of it, as soil degradation is often coincident with extreme

Figure 1: Proportion of the sample purchasing biochar as a function of price, over three seasons of biochar sales. Green, blue, and red areas give proportions for the long rains of 2014, the short rains of 2014, and the long rains of 2015. Long rains 2015 data is preliminary – sales have not completely concluded for the season. Lines give absolute proporitons, 95% confidence intervals generated via bootstrap resampling.



poverty, and those in extreme poverty often find it difficult to value long-run benefits, such as those conveyed by biochar application to soil. Third, in contexts where there is heavy government subsidization of fertilizers, biochar may improve the efficacy of fertilizer use on more degraded soils. In our Kenyan context, it isn't clear that biochar subsidies are favored over fertilizer subsidies in terms of short-run benefit. However, it could find substantial use in specialized settings where (a) carbon sequestration is valued, (b) long-run agronomic benefits can be considered, and (c) populations are targeted based on expected high response.

2 Future Work

This project has generated strong evidence that biochar is profitable under smallholder management, but that subsidies are required at the initial stage of dissemination in order to attain high rates of adoption. By themselves, these are moderately useful findings. However, they also raise important questions, both from policy mechanistic perspectives. Scaling this pilot project outwards – both spatially and in time – would provide an excellent opportunity to answer them.

From a policy perspective, a critical question around subsidization of pro-poor technologies surrounds the "exit strategy." It is often desirable to use subsidies as a way to build markets for profitable goods, withdrawing them once the market has become sustainable. However, it is rarely clear when, how, and even if this can be done. In this project, we saw an increase in demand over three seasons – from near-zero demand at any price to substantial demand, albeit at reduced prices. It remains to be seen whether and how much this upward trend might continue if extended into the future, and whether willingness to pay higher prices might increase. A finding that demand continues to grow over time could serve as evidence that short-term subsidies do in fact lead to long-term adoption – particularly if the study is allowed to proceed long enough for the subsidies to be withdrawn while data is still being collected. Conversely, a finding that demand does not grow with time, even in spite of large apparent profits, could provide policymakers with a case for re-targeting scarce resources away from programs that seem like they should work, but where community participation has lagged.

From a mechanistic perspective, a longer-term research approach would allow us to solve persistent puzzles in the area of technology adoption and dissemination. In particular, we find that the effect of social influence is inverted-u-shaped in the second season – the effects are small when there is low network penetration, high when it is moderate, and low again when it is higher. This is a persistent finding in technology adoption studies, but it is not well-explained. Some economists have proposed that it may be driven by learning externalities – when there is high penetration, one can delay adoption while learning from one's neighbors, but then there is low penetration, it makes sense to experiment. While this explanation might be plausible, such a relationship could stem from myriad other dynamics. For example, it could be that farmers with more adopters in

their network are more likely to see an example of the technology failing than those with fewer farmers in their network. Distinguishing between these and other explanations would be facilitated by observing adoption decisions within a social network context over time.

From a practical perspective, expanding the scope of the study could help determine the degree to which biochar can improve the economic efficiency of fertilizer subsidy programs, which have become increasingly popular in the period since the food crises of 2008 and 2011. This study has found substantial complementarity between biochar and inorganic fertilizer, but given that we did not randomize fertilizer subsidies, we cannot reliably answer the question of how biochar and fertilizer subsidies would interact in practice.

Scaling the project outwards would improve external validity, both with regard to technology diffusion policy and with regard to biochar itself. The Western Kenya context is somewhat unique in Africa, and biochar might have different potential elsewhere – both agronomically and economically. Heterogeneity in soils, population density, and availability of biomass – as well as market institutions, infrastructure, labor availability, and land tenure arrangements – are all likely to affect biochar's viability. Similar differences might also affect the relative efficacy of social learning versus subsidies – consistent results across contexts would lend these results enormous credibility, while a finding of substantial differences between contexts would serve as warning to policymakers against importing models from elsewhere that might not be appropriate.

3 Scaling/Dissemination plan

Ultimately, effective dissemination of the biochar will have to be led by the private sector. However, the experience of this project has shown that public sector involvement may be critical given that farmers may not be in a position to value longer-term benefits or positive environmental externalities. The proposed future work, above, gives a research agenda for determining how this might be made to happen effectively.

At the beginning of our intervention, our project was a close partnership with Re:char Kenya Ltd, and our scaling plan centered on this partnership. Re:char's failure to develop a sustainable market provides important lessons on how to do and not to do biochar dissemination. First, pro-poor technologies that involve lumpy investments – common in agriculture – might not succeed without substantial subsidization in the beginning. Re:char began its work by selling a biochar production kiln at KSh4,000 ($45). This is a huge sum for many farmers in the region, and substantially inhibited sales. However, even those that did buy it did not use it sufficiently to make an appreciable difference in their yields (it can be labor-intensive to operate), leading to little social effect of adoption. Taken together, we conclude that new technologies aimed at the poor need to be simple, cheap, divisible, and unambiguously effective. While many farmers do make substantial investments (in fertilizer for example), they are often much more certain about

the returns. Facilitating experimentation with new products requires that experimentation can be done first on a small scale. However, small-scale experimentation by potential customers may be quite difficult for a purely-private business that needs to show returns after a short period. This is particularly a problem in agriculture, when timeframes for experimentation are measured in years. As such, public sector intervention may be required at the outset. Coupled with rigorous research, continuous feedback can guide project continuance or closure as successive rounds of results become available.

Initially, our project envisaged a technology-centric scaling plan. Assuming that demand would exist, our original scaling plan centered on supply chains for the dissemination of Rutuba kilns. It is now apparent that supply chain creation is a second-order concern – biochar production equipment can be made by a skilled welder given sheet steel and oil drums. Based on what we now know, a scaling plan must involve support for farmers during initial stages of experimenting with biochar, coupled with research to ensure that the support provided remains warranted. Finally, provision of biochar itself for sale is likely to be substantially more effective than provision of equipment for its production – at least in initial stages.

During the next phase of this approach, local institutions with an interest in carrying this work from pilot scale to moderate scale will need to be identified. As we scale outwards, we'll require partners both to do the work of outreach, demonstration plot establishment, and sales. We'll also need to identify and develop the capacity of private sector partners to service this nascent market. Collaborations with fertilizer companies, NGOs, or government extension agencies may be appropriate, depending on the context. The key will be to build their capacity to sustainably provision the market with biochar as the project shifts from pure research to pure implementation, and as the market shifts from a heavily subsidized one to a normal one. As yet, no firm commitments from such partners have been secured, though outreach efforts are underway with representatives of local government, as well as regional NGOs.

In the meantime, the project will yield 1-2 academic publications, and has also attracted attention from journalists working for *Nature* magazine[1], and PBS's *NovaNext* (forthcoming).

[1] http://www.nature.com/news/agriculture-state-of-the-art-soil-1.16699