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The unintended consequences of agricultural input intensification:

Human health implications of agro-chemical use in Sub-Saharan Africa

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Introduction

The use of modern agricultural inputs has the potential to significantly boost agricultural productivity, a goal critical to structural transformation.

- Well-established in theory: *Johnson, Hazell, Gulati (2003); Johnston and Mellor (1961); Schultz (1964)*
- New empirical evidence supports a causal link between input use → ag productivity growth → economic growth: *McArthur and McCord (2014)*

However, may not be without risks of negatively affecting human health or the surrounding environment, thereby decreasing net productivity and well-being in the short and/or longer run.

Potentially opposing effects call into question the narrow policy objective of simply promoting the increased use of modern agricultural inputs.

May be most true of **agro-chemicals** (pesticides, fungicides, insecticides)

Important cautionary example: pesticides had overall negative effect on productivity in rice producing area of the Philippines: *Antle and Pingali (1994)*

What about Sub-Saharan Africa?

Descriptive evidence and anecdotal accounts are worrying:

- Available chemicals can be types banned in other countries
- Often sold in unmarked containers (informal market)
- Weak regulatory environment
- Little to no protective clothing or equipment used during application

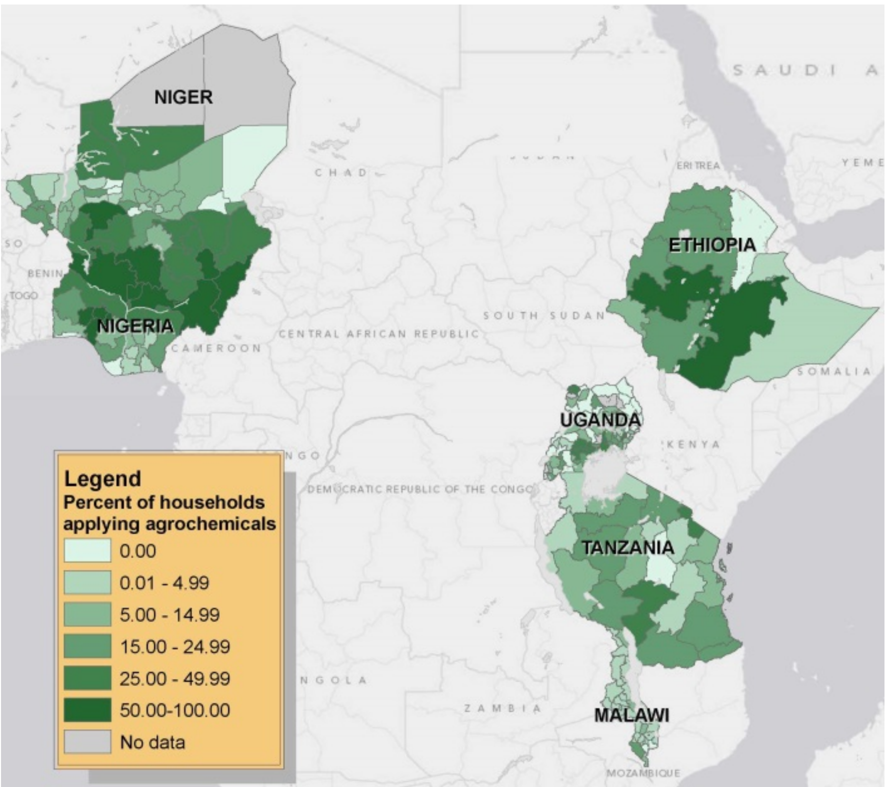
Most research on the costs and benefits focused on small sample sizes in cotton or rice producing areas where agro-chemical use is known to be high: *Ajayi and Waibel (2003); Maumbe and Swinton (2003); Ngowi et al. (2007); Ugwu et al. (2015)*

New nationally-represented descriptive evidence shows agro-chemical use is more widespread than commonly acknowledged **(16% of households in 6 countries)** and not confined to particular crops: *Sheahan and Barrett (2014)*

A more careful, empirical look at the potential trade-offs seems overdue.

Introduction

Percent of households using agro-chemicals



Source: Sheahan and Barrett (forthcoming)

We use data from four countries ***(Ethiopia, Nigeria, Tanzania, Uganda)*** to investigate the link between agro-chemicals use and:

- agricultural productivity
- health outcomes and health care costs

We motivate our analysis with a simple model that explores the role of information in identifying optimal application levels.

Contributions:

- Nationally representative panel data, spanning all cropping systems
- Multiple country investigation
- Include not just ag-laborers, but all members of farming households

Benefits of agro-chemical use:

- Direct benefits to farming households
  - Reduces the incidence of the pests and insects that can limit yields and contribute to both pre- and post-harvest losses
    - Increase in yields → increased incomes, decreased malnutrition, and improved human health
    - Revenue gains → more cash to purchase nutrient-rich foods or preventative health practices
  - Reduces the drudgery associated with hand-weeding, which may increase quality of life and decrease energy expenditure, physical hardship, injury

- Indirect benefits to larger community
  - Consumers benefit through increased food supply and decreased food prices when not well-integrated into national/global food markets
  - Release of labor from manual agricultural tasks may also contribute to more vibrant and economically diverse rural areas

Costs to agro-chemical use:

- Agro-chemicals are often toxic to humans
  - Negative neurological, respiratory, immunologic, and reproductive effects
  - Linked to diagnoses of cancer
  - Damage human immune systems
- Direct effects on agricultural laborers who apply chemicals on farm
  - Especially when applied without protective clothing/equipment
- But non-laborer members of farming households also likely to come into harmful contact
  - Walk through or play in fields near household dwelling
  - Chemicals may be stored in home
  - Re-use chemical containers for water or stored grains
- Negative impacts on environment may degrade agricultural productivity and/or human health over time
  - Run-off into water used for drinking and irrigation
  - Degradation of beneficial soil micro-organisms and the sorption or binding of important organic or mineral components

Model

To better understand how information about the adverse human health impacts of agro-chemical use might affect a farmer's choice of optimal application levels, we offer a simple dynamic optimization model of agro-chemicals use with current and/or dynamic feedback on human health.

$$L = \max_{c_t, v_t} \pi = \sum_{t=0}^{\infty} \rho^t [f(v_t, c_t | H_t) - r \cdot v_t - p \cdot c_t - w \cdot H_t - d \cdot I(c_t)$$

$$\text{s.t. } H_{t+1} - H_t = g(H_t, c_t) \text{ and } \underline{H} > 0$$

$\rho \in [0,1]$: intertemporal discount rate
$f(\cdot)$: agricultural production function
v_t: composite variable factors of production (like land and fertilizer)
c_t: agro-chemical inputs
H_t: quasi-fixed health-adjusted stock of labor
r, p, and w: prices of inputs (respectively)
$I(c_t)$: contemporaneous adverse human health effects that are triggered if and only if application surpasses a threshold level of safe exposure, $\hat{c}$
d: present period costs of addressing ill health induced by agro-chemical use in excess of $\hat{c}$

Model

The piecewise state equation $g(\cdot)$ that describes the impacts of current period use of agro-chemicals on the health-adjusted stock of labor in the next period H_{t+1}:

$$H_{t+1} \equiv g(H_t, c_t) = \big(1 - a(c_t)\big)H_t$$

$$a(c_t) = 0 \; if \, c_t \le \hat{c}$$
$$a(c_t) = \gamma c_t \; if \; c_t > \hat{c}$$

where $\gamma > 0$, $\hat{c} > 0$, and $\frac{\partial g(\cdot)}{\partial c_t} \le 0$.

γ: health degradation parameter

Model

The optimal agro-chemical input level ${c_t}^*$ is found by evaluating the current value Hamiltonian, incorporating the state equation that describes farmer health and λ_{t+1}, the shadow price for labor supply in period *t+1*.

$$\frac{\partial f(\cdot)}{\partial c_t} = p + d \cdot I_c(\cdot) - \rho\lambda_{t+1} \cdot \frac{\partial g(\cdot)}{\partial c_t}$$

Main take-away points:

1. Increasing c_t improves current period agricultural productivity but may hurt future productivity by harming human health.
2. Optimal rate of agro-chemical application for the farmer is the highest rate of application at which the future, discounted deterioration of laborer health does not outweigh the current marginal productivity gains.
3. If the farmer is completely unaware of or ignores the prospective adverse health effects from agro-chemical use, $\hat{c} = \infty$, then the farmer's optimal input level is necessarily higher than if she accounts for those costs directly.

Model

Because we do not know $f(\cdot)$ and $g(\cdot)$, we cannot solve for ${c_t}^*$.
A test of the three hypotheses that underpin the analytical results serves as a substitute:

$H_0: \frac{\partial f(\cdot)}{\partial c_t} = 0$ vs. $H_A: \frac{\partial f(\cdot)}{\partial c_t} > 0$ → Agro-chemicals increase crop output

$H_0: \frac{\partial dI(\cdot)}{\partial c_t} = 0$ vs. $H_A: \frac{\partial dI(\cdot)}{\partial c_t} > 0$ → Agro-chemicals increase health care expenditures

$H_0: \frac{\partial g(\cdot)}{\partial c_t} = 0$ vs. $H_A: \frac{\partial g(\cdot)}{\partial c_t} < 0$ → Agro-chemicals decrease labor availability

Rejection of each of these nulls in favor of the one-tailed alternate hypotheses would suggest that we may worry about the overall productivity effects of agro-chemical application levels.
This is the focus of our empirical investigation.

Data and variables

Data: Living Standards Measurement Study Integrated Surveys on Agriculture (LSMS-ISA), collected by national statistical agencies in partnership with the World Bank

Sample: any sampled household cultivating at least one agricultural plot in the main growing season

Country	Survey years included	Number of households
Ethiopia	2011/12 (Y1)	2,783
	2013/14 (Y2)	2,994
Nigeria	2010/11 (Y1)	2,739
	2012/13 (Y2)	2,814
Tanzania	2008/09 (Y1)	2,040
	2010/11 (Y2)	2,320
	2012/13 (Y3)	2,957
Uganda	2009/10 (Y1)	1,754
	2010/11 (Y2)	1,913
	2011/12 (Y3)	1,925

We include the four LSMS-ISA countries where ***at least 10% of sampled households used agro-chemicals*** *in main growing season from cross-sections included in Sheahan and Barrett (2014).*

Data and variables

Agro-chemical use: observed at plot level (binary), aggregated across types in Tanzania and Uganda while specific to agro-chemical type in Ethiopia and Nigeria

Human health outcomes/costs: observed at individual level, not specific to agro-chemical exposure or poisoning but refer to the general incidence of sickness, not all countries have all variables

1. Value of health expenditures related to recent illness
2. Value of time lost from work due to illness
3. Number of days lost from work due to illness
4. Binary variable where someone lost any time from work
5. Binary variable where someone fell sick in the recent past
6. Binary variable where someone recently visited a health worker due to illness
7. Binary variable where someone has a long-term or chronic illness

Value of harvest: observed at plot level, aggregated across all crops, calculated using methodology from the Rural Income Generating Activities (RIGA) project

Estimation

Crop productivity outcomes associated with agro-chemical use

$$y_{jkgt} = \beta_0 + \beta_1 c_{jkgt} + \boldsymbol{\gamma v_{jkgt}} + \tau_t + \varphi_{gt} + \omega_{kg} + \varepsilon_{jkgt}$$

Subscripts:

j plot
k household
g administrative area
t main growing season

Variables:

y is the value of all harvest at the plot level (inclusive of all crops)
c is the binary agro-chemical use variable
$\boldsymbol{v}$ includes all observed plot level characteristics and other inputs
τ is a survey and cropping year fixed effect
φ is an administrative unit fixed effect that varies by year
ω is a household fixed-effect
ε is a random error term

Estimation

Human health outcomes/costs associated with agro-chemical use

$$\boldsymbol{h}_{\boldsymbol{kgt}} = \rho_0 + \rho_1 c_{kgt} + \theta_t + \mu_{gt} + \epsilon_{kgt}$$

<u>Subscripts:</u>

k household
g administrative area
t main growing season

<u>Variables:</u>

$\boldsymbol{h}$ is the vector of health outcomes/costs
c is the binary agro-chemical use variable
θ is a survey and cropping year fixed effect
μ is an administrative unit fixed effect that varies by year
ϵ is a random error term

Results

Crop productivity outcomes associated with agro-chemical use

- Agro-chemical use is associated with positive and statistically significant increases in the value of harvest on a given plot:
  - Ethiopia: +19-32 USD
  - Nigeria: +68-85 USD
  - Tanzania: +40-62 USD
  - Uganda: +38-52 USD
- When using the natural log-transformed version of the value of harvest, remarkable similarity in magnitude on the agro-chemical coefficient estimate across Ethiopia, Tanzania, and Uganda:
  - ~33% increase in harvest value
- <u>Not</u> production function estimates and <u>not</u> causal
- Sizable, consistent, positive partial correlation estimates strongly suggest agricultural productivity gains associated with agro-chemical use

Results

Human health outcomes/costs associated with agro-chemical use

1. Value of health expenditures on account of illness/sickness
   - In Tanzania and Uganda, positive and significant effects in both the OLS and Tobit specifications.
   - In Nigeria, the statistically significant effects only emerge in the Tobit specifications, likely due to high number of zero values.

2. Value of time lost from work due to illness/sickness
   - In Ethiopia and Nigeria, the estimated effects are only positive and statistically significant in some Tobit specifications.
   - In Uganda, we observe three specifications (both OLS and Tobit) with positive and statistically significant effects.

3. Number of days lost from work due to illness/sickness
   - Mostly similar relationships emerge, but with increased significance in Nigeria and Uganda and decreased significance in Ethiopia (different recall periods).

Results

Human health outcomes/costs associated with agro-chemical use

4. Binary for *any* days missed from work due to illness/sickness
   - Positive and statistically significant relationships across most specifications.
   - With above, suggests that households that use agro-chemicals are indeed more likely to lose some work time and potential income as a result of illness/sickness.

5. Binary for household member fell sick in the recent past
   - In Ethiopia and Nigeria, remarkable similarity in the positive and statistically significant estimated correlations (at the 10 percent level).
   - In Uganda, these estimates are only positive and significant in two specifications.

6. Binary for household member recently visited a health worker
   - Positive and statistically significant relationships regardless of where we are able to isolate visits on account of actual illness.

7. Binary for longer term or chronic sickness
   - In Ethiopia, no effects (only observe where sick for >3 months)
   - In Nigeria, positive and significant effects (question specific to visiting a health worker because of a long term or chronic illness)

Results

Human health outcomes/costs associated with agro-chemical use

Other findings and thoughts:

- In Ethiopia and Nigeria, **herbicide** use accounts for all of the estimated human health relationships (also most common agro-chemical type)
- Not causal, but the consistent positive association is clear in the data (across countries and variables) and consistent with prior evidence from elsewhere

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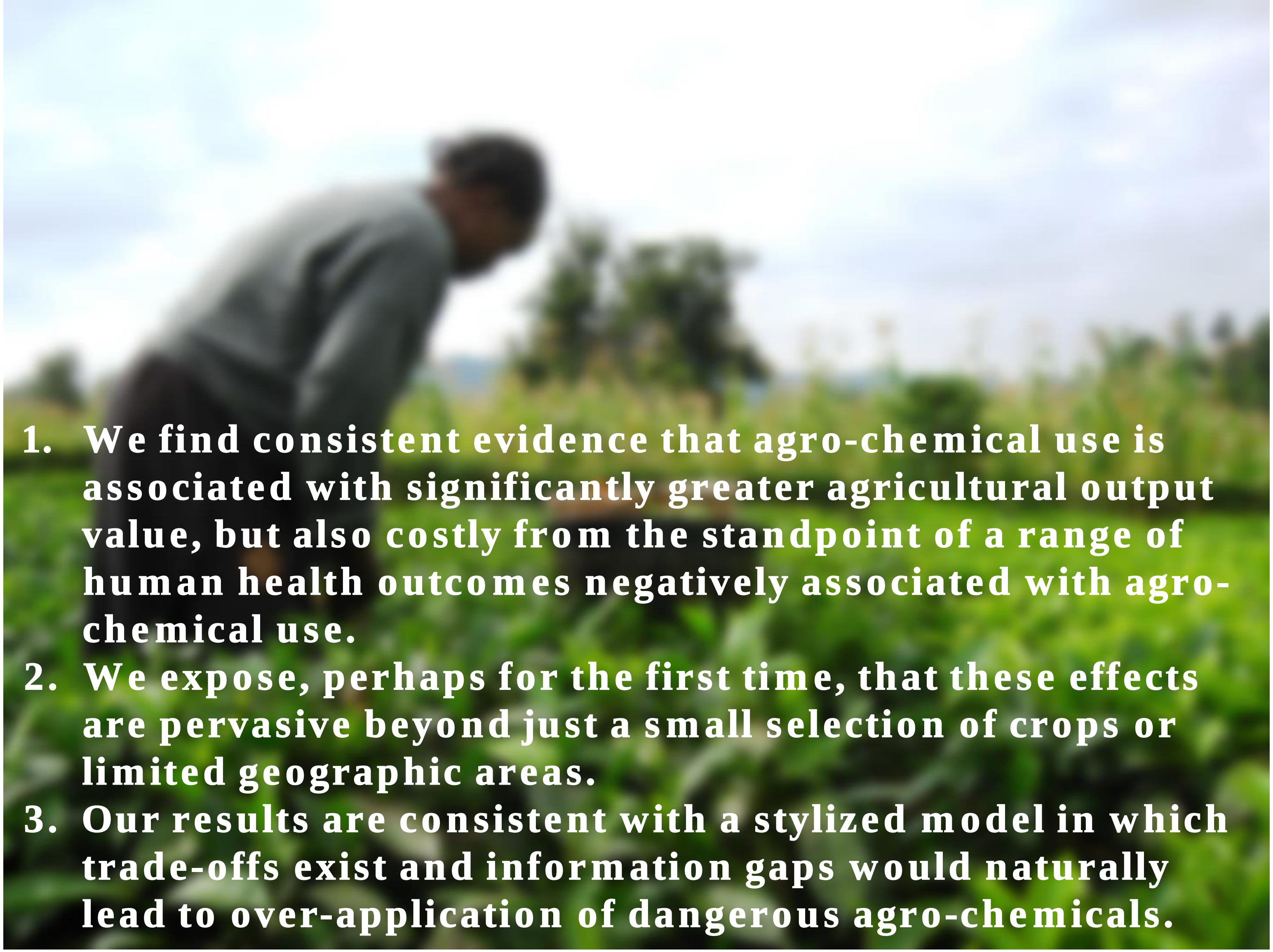
Conclusions



1. We find consistent evidence that agro-chemical use is associated with significantly greater agricultural output value, but also costly from the standpoint of a range of human health outcomes negatively associated with agro-chemical use.
2. We expose, perhaps for the first time, that these effects are pervasive beyond just a small selection of crops or limited geographic areas.
3. Our results are consistent with a stylized model in which trade-offs exist and information gaps would naturally lead to over-application of dangerous agro-chemicals.

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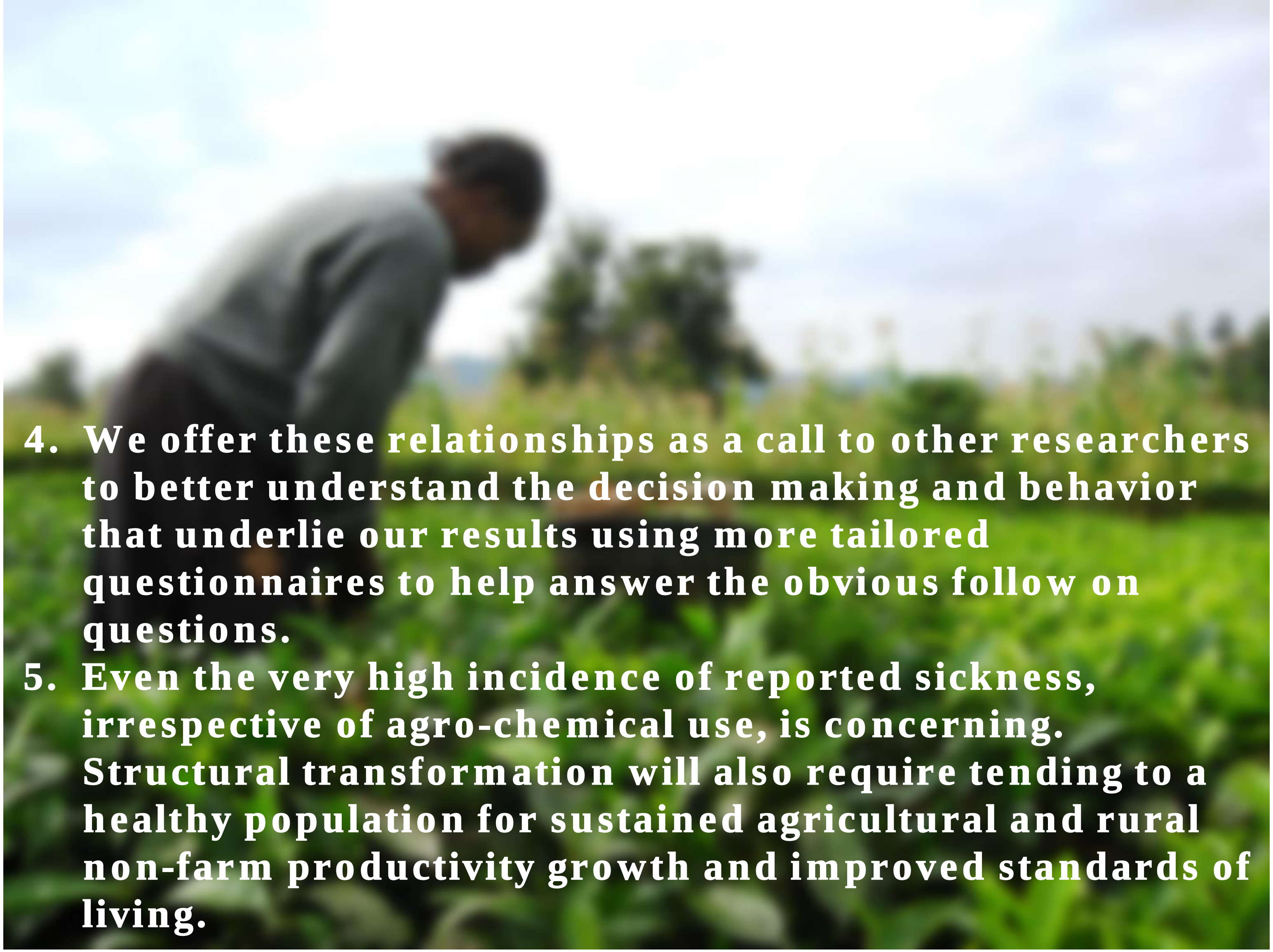
Conclusions



4. We offer these relationships as a call to other researchers to better understand the decision making and behavior that underlie our results using more tailored questionnaires to help answer the obvious follow on questions.
5. Even the very high incidence of reported sickness, irrespective of agro-chemical use, is concerning. Structural transformation will also require tending to a healthy population for sustained agricultural and rural non-farm productivity growth and improved standards of living.

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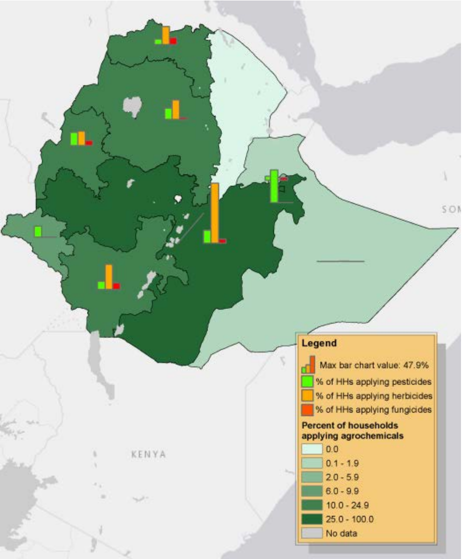
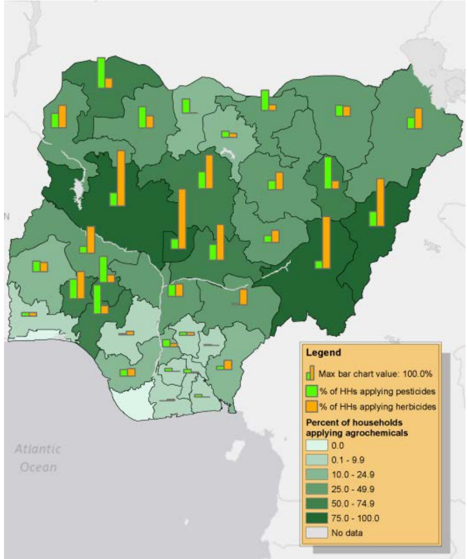
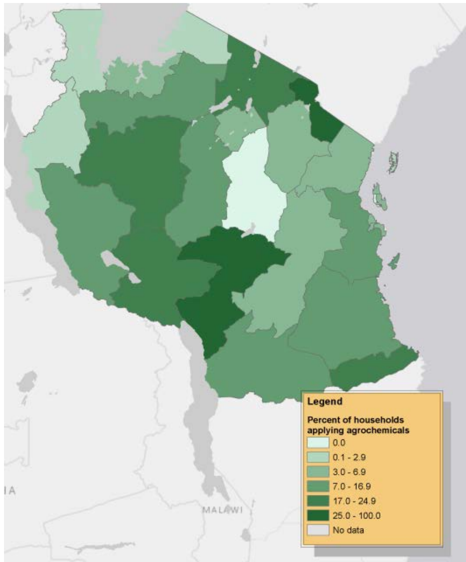
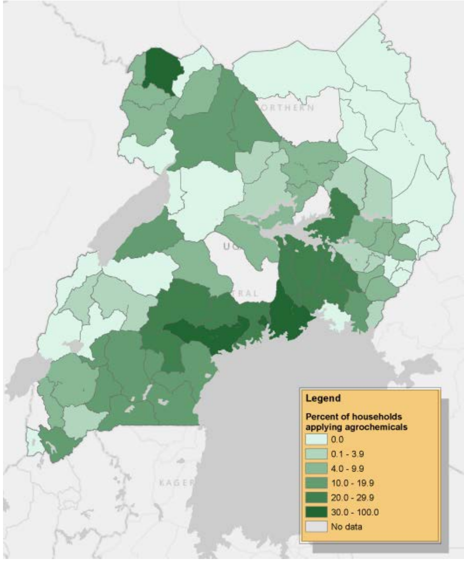
Thank you!









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