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Gender and inorganic nitrogen: what are the implications of moving towards a more balanced use of nitrogen fertilizer in the tropics?

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ABSTRACT

For agriculture to play a role in climate change mitigation strategies to reduce emissions from inorganic nitrogen (N) fertilizer through a more balanced and efficient use are necessary. Such strategies should align with the overarching principle of sustainable intensification and will need to consider the economic, environmental and social trade-offs of reduced fertilizer-related emissions. However, the gender equity dimensions of such strategies are rarely considered. The case studies cited in this paper, from India, Lake Victoria in East Africa and more broadly from sub-Saharan Africa (SSA), show that the negative externalities of imbalanced inorganic N use in high- and low-use scenarios impact more strongly on women and children. We examine, through a literature review of recent work in SSA, the relative jointness of intra-household bargaining processes in low N use scenarios to assess the degree to which they impact upon N use. We suggest that gender-equitable strategies for achieving more balanced use of N will increase the likelihood of attaining macro-level reductions in GHG emissions provided that they secure equity in intra-household decision-making and address food security. Gender-equitable N use efficiency strategies will help to integrate and assure gender and social equity co-benefits at local scales.

KEYWORDS

Inorganic fertilizer; nitrogen use efficiency; mitigation; gender; low-emissions development; India; sub-Saharan Africa

Introduction

Nitrogen (N) inputs to agriculture mainly comprise inorganic fertilizers, manure, biological N fixation and to a much smaller extent atmospheric N deposition. Whilst the contribution of different N sources to agriculture vary widely over space and time, the greatest change by far has been the rapid growth in use of inorganic N fertilizer since the 1960s, with further increases of around 40–50% expected over the next 40 years (Sutton et al., 2013). As it is the trend in use of inorganic rather than organic sources of N that have the most serious implications for human and environmental health, it is this form of N that serves as the focus of the present paper. There has been extensive research on the biophysical and economic impacts of N fertilizer use including income (Sapkota et al., 2014), crop and livestock production (Bouwman et al., 2013), soil health (Saha, Mishra, Majumdar, Laxminarayana, & Ghosh, 2010), biodiversity loss (Clark et al., 2013; Stoate et al., 2001), N_2O emission (Bellarby et al., 2014; Sapkota et al., 2015) and water quality (Butler et al., 2013). Constraints to use include price factors, limited access to input and output markets, credit constraints and weather risk (Karlan, Ratan, & Zinman, 2014; Ricker-Gilbert, Jayne, & Chirwa, 2011). Few studies

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have examined the gendered implications of high, low and balanced N use, particularly in the context of the imperative to secure food requirements from local to global scales whilst securing low-emissions development (LED) and protection of the environment.

This is an important gap given that a significant expansion in the use of inorganic N fertilizer over the coming decades is expected to occur in developing countries as a consequence of population growth and increasing food demands. In these countries women play a significant, though varied, role as farmers (FAO, 2010; IAASTD, 2008; Kristjanson et al., 2010; O'Sullivan, Rao, Banerjee, Gulati, & Vinez, 2014; Peterman, Behrman, & Quisumbing, 2010; World Bank, 2007). Some regions are experiencing a feminization of agriculture in locations as far apart as the State of Bihar in India, northern Vietnam and Malawi, as men migrate or become involved in more lucrative occupations locally (Andersson, 2006; Lastarria-Cornhiel, 2006; Mehar, Mittal, & Prasad, 2016; Paris & Rola-Rubzen, 2009; Pretty, Toulmin, & Williams, 2011). Although women may gain more decision-making power as de facto heads of household, such households may be more vulnerable to shocks as a consequence of women's generally weaker human and social capital, lower availability of male labour, lower access to input and output markets, lower access to agricultural technologies and machinery, lower access to credit and collateral and lower access to extension advice – including on how to mitigate and adapt to climate change (FAO, 2010; Farnworth & Colverson, 2015; Manfre et al., 2013; O'Sullivan et al., 2014; Ragasa, Berhane, Tadessa, & Seyoum, 2013; Shiundu & Oniang'o, 2007). Women may also forgo food to ensure that children and other family members eat nutritious food (Akerele, 2011; Ramachandran, 2012, 2014; Sugden et al., 2014). It is in this broader context that interventions to achieve a more balanced and efficient use of inorganic fertilizer N should be considered.

It is recognized that in order to increase crop production in a sustainable manner a combination of good agronomic practices are required including the use of improved seed, crop rotations and diversification, application of organic matter (from plants and farm manure) together with balanced and judicious use of inorganic fertilizer that includes lime where low pH is a problem. Integrated approaches have been captured in paradigms such as integrated soil fertility management (Roobroeck, van Asten, Jama, Harawa, & Vanlauwe, 2015; Vanlauwe et al., 2010; Zhang et al., 2015) and conservation agriculture (Palm, Blanco-Canqui, DeClerck, & Gatere, 2013; Powlson, Stirling, Thierfelder, White, & Jat, 2016; Sapkota et al., 2017; Thierfelder, Mwila, & Rusinamhodzi, 2013). As well as raising production, reducing post-harvest losses – which can amount to between 20% and 35% of production – presents an important means of meeting food demands whilst saving land, water and fertilizer and so forms an essential part of any sustainable intensification strategy (Stirling et al., 2014).

A widely accepted set of best fertilizer management practice in crops is termed the '4Rs' – the four 'rights'. These provide a framework to guide farmer decision-making regarding the right source of nutrient, applied at the right rate, at the right time and in the right place (Richards et al., 2016). Sound agronomic practice is a pre-requisite for the 4Rs including making best use of available organic inputs, planting date, cultivar choice, spacing and early weeding (IPNI, 2012; Richards et al., 2016; Tittonel & Giller, 2013). However, applying a gender lens suggests that women and men may not have the opportunity to apply these simple principles equally. Even if they are trained, women may find it more difficult to apply the practical knowledge than men for some of the reasons outlined above. There is wide consensus that gender gaps in access to inputs lie, in part, behind observed differences in productivity. Doss (2015) divides arguments for targeting investments in agriculture to women into two main strands. One strand posits that women are heavily involved in agricultural production in the developing world, particularly in sub-Saharan Africa (SSA), but have been neglected in the majority of development initiatives. This suggests that the returns to targeting women farmers, for example in relation to promoting best practice N use, may be very high with respect to increasing aggregate production and women's incomes. The second strand argues that women should be key beneficiaries in development efforts due to their instrumental role with respect to child health, nutrition and education. These two strands are not mutually exclusive. Taken together, they make the case that the social returns on agricultural investments are higher when targeted to women. The chain of efficacy rests on a complex causal chain: (i) investments can selectively drive up women's productivity, (ii) these investments will produce benefits for women (and children) and (iii) the rates of social return for such investments will be higher than for other investments (Doss, 2015). However, each of these assume that women

have a strong say in intra-household decision-making processes and are able to secure benefits commensurate to their work. In this paper, we examine these assumptions critically.

We hypothesize that in low fertilizer N use situations gendered inequalities in access and use of fertilizer creates an ever-deepening negative feedback loop of lower yields, lower income and potentially harmful knock-on effects on household food and nutrition security on women-managed plots. At the other end of the spectrum, women farmers living in high N use environments experience a number of gendered impacts. Their health, and that of children, may be negatively affected by nitrites in water, for instance in paddy (Brainerd & Menon, 2014; Udeigwe et al., 2015). We suggest that moving towards a more balanced and efficient use of fertilizer N will significantly improve gender and social equity outcomes, though change will ultimately be reliant on significant shifts in locationally specific deep structures informing gender and social norms.

The paper opens with a discussion of low, high and balanced N use efficiency (NUE) scenarios, comparing NUE for different regions of the globe. Following this, the second part of the paper presents three case studies which highlight the implications of high and low inorganic N use for gender in relation to health outcomes. They are taken from India, Lake Victoria in East Africa and more broadly from SSA. The findings show that outcomes are complex, wide ranging and surprising. We then move to the third part of this paper. Given that gendered inequalities in the rural advisory services and to a lesser extent in policy – particularly around subsidies – have been well explored, we focus our discussion on recent research on how intra-household decision-making on input allocations, and the distribution of benefits, influences the application of inorganic N fertilizer to women-managed, men-managed and jointly managed plots.

We conclude by suggesting gender-equitable strategies for achieving more balanced use of N. We expect that this will increase the likelihood of attaining macro-level reductions in GHG emissions through increasing NUE across all plots in low N use systems. At the same time, gender-equitable NUE strategies will help to integrate and assure gender and social equity co-benefits at local scales.

Towards a more balanced use of N

Agricultural systems are leaky with the result that only a fraction of the applied N ends up in harvested products. Globally, NUE on croplands has declined by about 20% to just under 50% since the early 1960s (Lassaletta et al., 2014) but this hides large regional variation (Figure 1). Applied N, if not taken up by the crop or immobilized in soil organic N pools, is vulnerable to losses from volatilization of ammonia (NH_3), leaching of nitrate (NO_3) and emissions of nitrous oxide (N_2O) and nitric oxide (NO) following nitrification–denitrification reactions, all of which can have a range of negative on-site and off-site environmental consequences (Baulch, 2013).

Achieving synchrony between N supply and crop demand without excess or deficiency in use is therefore key to optimizing trade-offs among yield, income and the environment. Agricultural systems need to function within a 'safe operating space' for N use (Raworth, 2012) where NUE is neither too high that soils are being mined and degraded, nor so low that large amounts of reactive N are being lost to the environment. Figure 1 summarizes the efficiency of NUE for different regions of the world where N-use can be characterized as 'balanced', as in the case of much of Europe (e.g. see Stoate et al. 2009), overused as in the case of China, and underused as in the case of much of SSA. The following takes a closer look at the two environments of interest to our paper in which N use is high and low.

Low N use environments

In some regions of Latin America and Asia, and across almost all of SSA, too little N fertilizer is used for production, contributing to soil nutrient mining, soil degradation and low productivity (Sanchez, 2002; Tully, Sullivan, Weil, & Sanchez, 2015). It is difficult to accurately determine soil nutrient depletion and loss of organic matter because flows such as leaching, soil erosion, wet/dry deposition and N_2 fixation are hard to measure. However, in SSA – regardless of how they are calculated – nutrient balances almost always show negative values (Spalding & Exner, 1993; Tittonel & Giller, 2013). Across SSA cereal yields are low and stagnant, averaging 1.3 t ha^{-1} compared with 3 t ha^{-1} in the developing world as a whole (Milder, Majanen, & Scherr, 2011). In Kenya, for example, only one-third of total cultivated maize is fertilized even though it is the country's most important staple food crop and accounts for 40% of all fertilizer applied at the national level (Sheremenko & Magnan, 2015). In Ghana and Sudan overall fertilizer consumption is 4 kg/ha compared to 383 kg/ha in Egypt and 106 kg/ha in Brazil (FAO, 2006a). Food

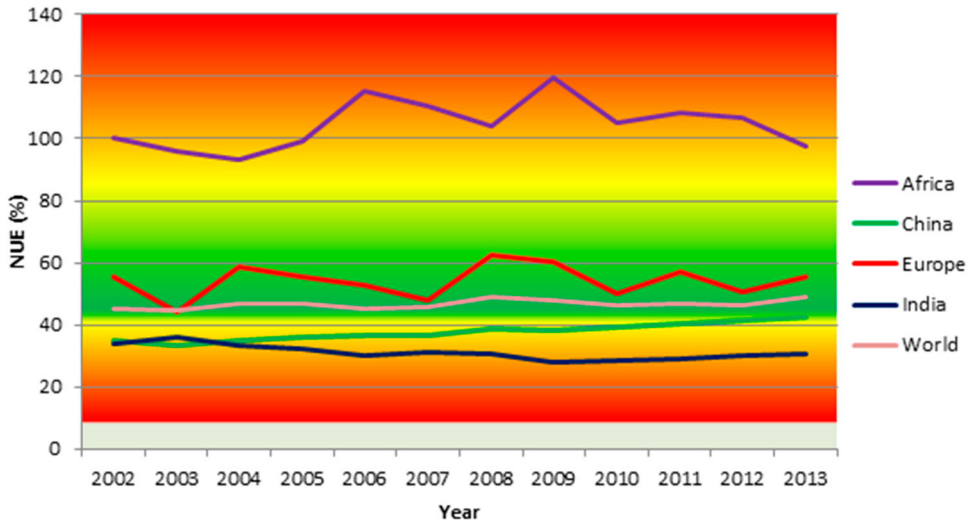

Figure 1. Summary of the N use efficiency (NUE%) of crops for different regions of the world. Data are taken from FAOSTAT for period 2002–2013 and each line is the mean calculated for the following crop categories: All cereals, root and tubers, oil crops, pulses and vegetables and melons (adapted and updated from Brentrup & Palliere, 2010).

production is increasing at about 2% a year whereas an annual increase of between 4% and 7% is required to meet the food needs of the population in general in SSA (FAO, 2009). The baseline scenario is that, in many cases, both women and men small-scale farmers, regardless of household typology, do not apply sufficient fertilizer, including inorganic and organic N, to their plots.

Gender is not the only factor in low adoption of fertilizer (Tittonel & Giller, 2013). Low use should be contextualized within the broader complex of causes of low productivity in sub-Saharan African smallholder agriculture. These include generally weak access to input and output markets, intense labour demands caused by the lack of mechanization, the small size and increasing fragmentation of farms, and a lack of capital to invest in building soils in harsh environments (Tittonel & Giller, 2013). Each of these has a significant gender dimension, however, as discussed in the introduction and below.

High N use environments

In China and regions of South and Southeast Asia the situation is the reverse. In China, for example, NUE is declining from over 80% in the 1960s to around 40% in 2010 (Lassaletta et al., 2014). In some regions, rates of inorganic fertilizer N consumption are increasing exponentially. In 2002, N fertilizer consumption in North America and Europe was twice that of India but by 2013, India had overtaken these regions. Although there has been an increase in crop production in India over the same period the rate of increase in inorganic N use has been even greater (Lassaletta et al., 2014; Sutton et al., 2013), suggesting that use of N fertilizer in India may be excessive and inefficient. Some researchers argue that a major issue in India is imbalanced rather than over-use of N fertilizer which results in poor efficiencies of N uptake (Jat, Majumdar, McDonald, Sikka, & Paroda, 2015). In India, the effects of policy instruments since 2010 have been a substantial increase in the market price of P and K fertilizers, but not of N fertilizers, widening the fertilizer ($N:P_2O_5:K_2O$) consumption ratio from 4.3:2.1:1 in 2009–2010 to 6.8:2.4:1 in 2014–2015 (Jat et al., 2015.).

In contrast, fertilizer use in Europe increased rapidly up until the mid-1980s then stabilized thereafter with no detrimental effect on crop yield (van Grinsven et al., 2012). Such trends in fertilizer use indicate that improvements can be made in NUE. From past experience in regions such as Europe well-targeted policy instruments can help leverage action towards these goals (van Grinsven et al., 2012).

Gender implications of imbalanced N use: case studies

The gender implications of imbalanced use of inorganic fertilizer in high and low N environments are rarely considered. Gendered data are scattered in

the social science, health, hydrological and agronomic literature. A much larger number of studies, for example in relation to the impacts of excessive N on health, have been conducted in North America and Europe than in developing countries. In turn the lack of data and analysis contributes to gender-blind policy-making and programme development in many countries. The Fertilizer Input Subsidy Programme – FISP – in Malawi is an exception since female-headed (FHH) households are targeted alongside male-headed households (MHH) (Chirwa, Mvula, Dorward, & Matita, 2011). One assessment of the scheme showed that the probability of adopting modern maize was 12% lower for wives in male-headed households, and 11% lower for female household heads, than for male farmers. The receipt of subsidized input coupons had no discernible effect on modern maize adoption for male farmers but issuing subsidies for both seed and fertilizer increased the probability of modern maize cultivation by 222% for female household heads (Fisher & Kandiwa, 2014). Given that the Malawian FISP is widely discussed, and because our focus is not upon subsidized N use, we do not refer to it further here.

This section provides three cases studies on the gendered implications of imbalanced N fertilizer use in diverse scenarios. The first case study demonstrates clear associations between negative health outcomes for poor rural women and their infants and the timing of N fertilizer applications in India. The second case study suggests that the application of N to cash crops rather than food crops may contribute towards negative food availability and nutrition outcomes for family members in some sub-Saharan African countries. The third case study traces a complex pathway between low use of N fertilizer and soil erosion to the deposition of N in Lake Victoria and consequent health outcomes for women and men artisanal fishers.

Case study 1. Health effects in high N use environments

There has been concern around the potentially negative effects on N fertilizer use on human health for many years. In 2003 Townsend et al. summarized a large number of studies which suggest that the net public health consequences of the changing N cycle are generally positive at lower levels, since applications of N help to increase productivity and production. However, the benefits from increased production are increasingly traded with dis-benefits arising from reactive N losses to the atmosphere and water bodies (Udeigwe et al., 2015). Regarding airborne effects, a study conducted in Nigeria's N fertilizer production facility at Port Harcourt noted a large number of respiratory and other health issues associated with working at the plant and living within two kilometres of it (Ana, Sridhar, & Olawuyi, 2005). In Bangladesh, the application of N fertilizer appears to have an effect on groundwater arsenic pollution through enhancing microbial activity. This promotes the release of arsenic from peat sediments to groundwater (Uddin & Kurosawa, 2011). Associations between nitrate in drinking water and (a) infant methaemoglobinaemia and (b) cancers of the digestive tract remain controversial between scientists (Dar, Sankar, Shah, & Dar, 2012; Powlson et al., 2008).

A national study conducted in India (Brainerd & Menon, 2014), examining the impact of fertilizer agro-chemicals (defined here as any of the following: nitrogen, nitrates, phosphates, potassium, fluoride and chromium) in water on infant and child health, found that children exposed to higher concentrations during the first month after conception experience poorer health outcomes on a variety of measures. The study correlated data on the increase in fertilizer use over time in India, the differing timing of the crop planting seasons across India's states and fertilizer application, and the seasonally adjusted prenatal exposure of infants and children to N and phosphate in groundwater to isolate the impact of fertilizer agro-chemicals on child health. The study found that a 10% increase in the average level of agro-chemicals in water in the month of conception increases the likelihood of infant mortality by 4.6% with the percentage slightly higher (6.2%) for neo-natal mortality. The presence of agro-chemicals in water in the first month after conception was significantly associated with reductions in other measures such as height-for-age and weight-for-age for children below five years of age. This indicates that the actual month of conception exposure contributes to very long-lasting effects. Finally, the negative consequences of early agro-chemical exposure were not uniform. The effects were most pronounced among vulnerable populations, in particular the children of uneducated poor rural women. These women are generally strongly active in the agricultural labour force and are directly exposed to fertilizer applications, for example in transplanting rice seedlings and weeding (Brainerd & Menon, 2014; Paul, Meena, Singh, & Wani, 2015; Waris, Nirmala, & Kumar, 2016).

Case study 2. Associations between crop selection, N fertilizer use and household food security

This case study queries the assumption that improving rates of return to N by applying N primarily to crops destined for sale results in improved household level food security. For many food crops farmgate prices are low and so there is an unfavourable fertilizer/food price ratio (Affholder, Poeydebat, Corbeels, Scopel, & Tittonell, 2013; Djurfeldt, Holmén, Jirström, & Larsson, 2005; FAO, 2006a, 2006b; Geier, 1995). A farmer's financial resources including the availability and cost of credit, the conditions of land tenure, and adequate supplies and distribution facilities of fertilizer all impact upon willingness and ability to invest in fertilizer. Each of these has an additional gender dimension.

An analysis of a large data sets on land use and production from over 13,000 smallholder farms across 17 countries in SSA makes the case that improving market access for cash crops significantly strengthens food availability (i.e. *potential* supply of food available not *actual* availability) to households (Frelat, Lopez-Ridaura, Giller, Herrero, & Douxchamps, 2016). On average self-production provided 60% of food available to households with only 20% of households having their food needs fully met from self-produced crops. On this basis, the authors conclude that closing yield gaps of staple food crops will not necessarily improve food availability because the majority of farm households sell staples to generate money even though prices obtained are often low. They argue that increasing returns by promoting cash crops and intensifying livestock production is necessary in order to promote household level food availability. In turn, good market access allows farms to intensify production on small land parcels. The study acknowledges that effective functioning markets capable of avoiding product saturation are rare (Frelat et al., 2016). These conclusions are partly supported by Mathenge and Smale (2013) who show that, in Kenya, off-farm earnings have a negative effect on farmer willingness to invest in fertilizer for maize, a key food staple, but positive effects for fertilizer use on cash crops including vegetables, coffee and tea. Chirwa et al. (2011) show in Malawi that tobacco cultivation improves probability of fertilizer application by 8–14%, and use on maize for sale by 9–13%. Achterbosch, van Berkum, and Meijerink (2014) raise the concern that production for export may lower food availability in smallholder economies. The study finds that cash crops can bring substantial wage and employment opportunities to the rural economy and, over time, can be expected to stimulate agricultural innovation both on individual farms and in the wider economy, through raising capital for agricultural investment and accelerating the build-up of institutions that enable further commercialization. At the same time, however, the study notes that the smallholder sector is vulnerable to strong income fluctuations which may challenge some of these effects (Achterbosch et al., 2014).

It is useful to unpick the assumption that strengthened cash cropping will automatically result in more food availability in the household. Drèze and Sen (1989) remarked years ago that, 'The mere presence of food in the economy, or in the market, does not entitle a person to consume it'; this remark can be extended to households too. The access of women and men, boys and girls, to a healthy and sufficient food basket does not only depend on their ability to purchase or to grow it. Merely ensuring that enough food enters the market is insufficient to improve availability to the whole household, nor equitable access, adequacy, or nutritional quality and diversity. The Achterbosch et al. (2014) study acknowledges that there may be inequitable intra-household level distribution, but places further discussion beyond the remit of the paper. However, other studies suggest that monies made from the sale of cash crops are not necessarily returned to the family in the form of improved food availability and nutrition. A review by Bertelli and Macours (2014) provide a complex picture citing evidence for and against improved household nutrition and food security from strengthening cash crop production. Some studies cited show that improving subsistence food production has a higher impact on these indicators (Blanken et al. 1994; Peters and Herrera, 1994; Sahn and Davy, 1991, all in Bertelli & Macours, 2014). Several studies show mixed effects upon calorie consumption and nutritional status occasioned by leaving subsistence production altogether (De Walt, 1993; Govereh and Jayne, 2003; World Bank, 2007, all in Bertelli & Macours, 2014).

It is well established that gender relations and other socio-cultural inequalities may result in preferential allocations of food to adult males rather than to women and children within households, though the evidence is complex and sometimes contradictory (Preedy, Lan-Anh Hunter, & Patel, 2013). It has been documented for decades in countries as diverse as

Mexico, Brazil, Bangladesh and Malawi that men are often less likely than women to spend their money on household welfare (Chirwa et al., 2011; Quisumbing, Brown, Feldstein, Haddad, & Pena, 1995; Thomas, 1997). In many cases improving 'household' or male incomes, access to credit and other assets does not lead to the same impacts on child nutritional status and associated health incomes and educational attainments as increasing women's control over income (De Schutter, 2012; Jiggins, 1986; OECD, 2010). Akerele (2011) found in Nigeria that although households had sufficient nutritious food available, male and female school age children suffered deficits of 13.1% and 17.5% in their respective calorie requirements. Adult male members were the most favoured in terms of food calorie allocation relative to other members. The varying needs of girls and women across their life-cycle for specific nutrients and additional calories during childhood and adolescence, pregnancy and breast-feeding, and during menopause, may not be acknowledged (Gillespie & Haddad, 2001; Jackson, 1996; Ramachandran, 2012). There is some contrasting literature. In Malawi MHH households receiving fully subsidized fertilizer apply this to maize grown for household subsistence needs. This is the purpose of the subsidy. However, this effect diminishes for partly subsidized fertilizer and commercially bought fertilizer in MHH households (Chirwa et al., 2011).

On balance, these findings suggest that the benefits of N are sometimes directed to favoured household members or directly exported out of the farm system, generating food and nutrition costs for women and children in situations where access to food is gendered.

Case study 3. N loading and gendered health outcomes in Lake Victoria

Eutrophication poses a major challenge to the viability of fisheries worldwide and can lead to considerable biodiversity loss and concomitant reduction in ecosystem services (Gordon, Finlayson, & Falkenmark, 2010). In poorly managed, low-input as well as high-input systems, N and phosphorus from eroding soil can reach water bodies and contribute to eutrophication (TEEB, 2015; Zhou et al., 2014). In the Lake Victoria watershed, a large fraction of the N entering the lake is from eroded soil leading directly to negative, gendered health outcomes. In this case study we discuss the sources of N loading, trace the impacts upon artisanal fisheries of eutrophication, and present emerging data on health outcomes.

The success of the fishing industry in Lake Victoria has led to massive population pressure in all countries sharing the lake, resulting in approximately 30 million people drawing a livelihood directly and indirectly from the lake. However, although there are many challenges to its fishing industry, Kolding, Van Zweiten, Mkumbo, Silsbe, and Hecky (2008) isolate eutrophication is by far the most important threat to livelihoods. Nutrient inflows into Lake Victoria – particularly N and phosphorus, have led to a five-fold increase in algae growth since the 1960s (Kolding et al., 2008). Zhou et al. (2014) show that net N release in Lake Victoria at basin level is due primarily to livestock and human sources (https://outlook.live.com/owa/?path=/mail/inbox/rp#x__msocom_1) which contribute between 69% and 85%. They argue that levels of nitrogen release to the watershed are primarily derived from poor soil management due to imbalances in N with insufficient application of N fertilizers and poor rates of biological N_2 fixation. This results in soil degradation and soil erosion. Kayombo and Jorgensen (2006) note that many staple annual crops such as maize are grown without ground cover thus contributing to high levels of soil erosion and consequent loss of soil N in the Lake Victoria watershed. Appropriated wetlands and water hyacinth (*Eichornia crassipes*) infestation contribute to the decimation of fish breeding grounds (Mojola, 2011). Although water hyacinth is efficacious in removing excess N and phosphate (Kayombo & Jorgensen, 2006) it is prolific close to shores, reducing biodiversity and causing economic losses including a rapidly declining fish catch for small fishers (Kayombo & Jorgensen, 2006; Lowe, Browne, Boudjelas, & De Poorter, 2000). As a consequence more fishers – almost exclusively male – are seeking more, and ever smaller fish, and are travelling further to do so (Kayombo & Jorgensen, 2010; Mojola, 2011). Women are largely excluded from fishing and trading within the mainstream Nile perch economy (Lwenya & Yongo, 2012; Mojola, 2011) and rely on purchasing reject Nile perch and dagaa/omena (*Rastrineobola argentea*), a small sardine-like fish fished largely at night, for their livelihoods and family nutrition (Fiorella et al., 2015).

An increasing body of research (Béné & Merten, 2008; Fiorella et al., 2015; Mojola, 2011) is positing causal links between the changing ecological environment of Lake Victoria due to eutrophication, the gendered nature of the fish economy and human health.

The transformed ecological environment is reshaping social structures and reorganizing sexual, domestic and economic partnerships in ways that significantly increase their vulnerability to HIV/AIDS (Mojola, 2011). In all countries around Lake Victoria, HIV rates are very high. For instance, among fishing communities in Uganda HIV prevalence is three times higher than in the general population (Opio, Muyonga, & Mulumba, 2013). The disrupted lake and fish ecology is contributing directly to the 'fish for sex' economy whereby many women traders who purchase, process and retail fish (and are thus critical actors in the sector) acquire favoured access to fish through engaging in transactional sex, known as *jaboya* (Béné & Merten, 2008; Fiorella et al., 2015; Mojola, 2011). Female traders are travelling ever further between beaches and trading centres across the region to procure, process, transport and sell fish in markets for local consumption (Camlin, Kwena, & Dworkin, 2013). At the same time, male fishers are travelling further across the lake. Many such men maintain *jaboya* relationships with women on different beaches. The increasing prevalence of HIV/AIDS has, in turn, huge socio-economic impacts, including the death of women and men in their economic prime. This is not only a question of losing working hands; it leads to a loss of agricultural know-how contributing towards reduced agricultural production. In addition to reducing labour inputs, HIV/AIDS diminishes capital investments in agriculture since monies are spent on medical bills, funerals and on food purchases. Household assets may be stripped in distress sales occasioned by the need to pay for AIDS-related expenses, and as a result of property grabbing by relatives after the death of a spouse. Stigmatization more broadly may prevent households from participating in community networks, producer groups and other platforms (Torell et al., 2007). In turn, household members may turn to transactional sex to overcome increased vulnerability to shocks particularly in rainfed agricultural systems thus deepening the crisis (Burke, Gong, & Jones, 2015; Garba, Bala, & Ibrahim, 2015).

Intra-household decision-making on fertilizer N use

The three case studies show that both high and low N use scenarios can have gendered health outcomes. Discussions around the gender implications of policy (particularly subsidies), the gendered nature of many Rural Advisory Systems and other issues around access and control of resources are well covered in the literature. This section surveys recent literature which suggests that the type of intra-household decision-making prevalent in a location can play an important role in determining the distribution of N fertilizer to plots managed by women, by men and jointly. We use the term 'jointness' to suggest the wide spread of cooperation in household bargaining processes in preference to the dichotomous terminology of non-unitary and unitary models of household behaviour. Women and men have separate assets, activities, consumption, savings and investment strategies, but households also have joint assets, activities and consumption strategies as well (Quisumbing et al., 2014).

Low intra-household jointness in decision-making and fertilizer N use

There is widespread consensus that if women could use the same level of inputs – including fertilizer – on their plots as men this could raise total agricultural output (FAO, 2010; O'Sullivan et al., 2014). Much of this analysis is based on research suggesting that a causal factor of low female productivity is lack of jointness in farm management in many locations. Individual members of a household engage in separate agricultural production activities and may operate separate plots. Since the playing field is not level due to gender inequalities in intra-household decision-making around access to resources and resource allocation, so the argument goes, gender-differentiated productivity outcomes almost inevitably arise. These differentials diminish or are eliminated once input use is taken into consideration (Doss, 2015; Kassie, Stage, Teklewold, & Erenstein, 2015; Marenya, Kassie, & Tostao, 2015; Ndiritu, Kassie, & Shiferaw, 2014). These studies show that spouses often make distinct agricultural choices within the same household, implying that a unitary household bargaining model is incapable of analysing farming choices (Sheremenko & Magnan, 2015).

Doss and McDonald (1999) suggest that inefficiencies in fertilizer and other input allocations can occur because household members 'neither pool nor trade inputs with each other'. Doss (2001) argues that the reason why intra-household reallocation does not happen in some situations is because such exchanges can affect long-run bargaining power, even though in the short-run it could increase farm profits. Sen (1990) broadens this discussion by explaining that

household gender relations profoundly affect the intra-household distribution of commodities and the ability of each gender to use, and benefit from, particular commodities. Women and men may collaborate to different degrees to bring wealth into the family, but the division of wealth may be a source of conflict. In the case of separately managed plots, it may well be the case that women manage their own plots, but it does not necessarily follow that they derive sole benefit.

Doss (2015) remarks that the 'gender gap' literature is rarely based on an assessment of programmes which actually provide the same level of inputs to women to see if their production is comparable to that of men. It is not necessarily certain that women would achieve the same levels of production as men in smallholder production systems with the same amount of inputs because inputs are only one factor among others which determine production and productivity (Doss, 2015). It is also possible that complex intra-household decision-making processes and flows of resources may exist between apparently separately managed plots which to date have been insufficiently analysed. For instance, a Malian study (Collins & Foltz, 2013) shows that fertilizer use does not contribute greatly to the sharp gender productivity differential between female-managed and men-managed plots. The key factor in determining productivity is female labour availability; the yield differential lessens significantly when there are more women in the household to share labour with on female-managed plots. A second Malian study (Kazianga & Wahhaj, 2013) found that the gender differentials in productivity between female-managed and men-managed plots were accounted for by the plot manager's position – either as household head or as junior family member – rather than through differential application of inputs such as inorganic fertilizer, gender of the plot manager per se. Household heads, who were overwhelmingly male, achieved higher yields than other family members; females and males who were not household heads achieved similar yields to each other. This yield differential is caused by social norms that require that multiple household members contribute labour to plots managed by the household head; they are rewarded by the household head in the form of his spending on household public goods.

A study in Malawi (Farnworth, in press) found that women members of a coffee cooperative are far less likely to purchase inorganic fertilizer than male members on their coffee plantations, even though important productivity increases are likely to be secured and financial returns thereby significantly improved. The women explained that they cannot make investments into future gains because they currently experience significant difficulties in meeting basic needs including an inability to provide sufficient food, clothing and school fees for their children – all of which are primarily the responsibility of women. They felt unable to invest in the future – specifically in cash crops – when the present was not catered for.

By way of contrast a gender analysis of the Ethiopian Central Statistics Agency's Agricultural Sample Survey data, which were collected between 2010 and 2013 and covered more than 45,000 crop growers, shows that women in crop production have a substantially lower livelihood asset base than do men across all dimensions studied (Kasa, Abate, Warner, & Kieran, 2015). For instance, the size of plots managed by women is 43% smaller, on average, than the size of plots managed by men. About 12% of women land holders have two or more oxen, against almost one-third of men. Women are also much less likely to use improved seed. However, this lower asset base does not translate into a reluctance to apply fertilizer. Whilst the proportion of women who apply inorganic fertilizers is about 8% lower than men the proportion of fertilized area to the total crop area on plots held by women and the rates of fertilizer application were slightly higher than on plots held by men (Kasa et al., 2015). A Kenyan study provides similar findings, with female plot managers less likely to adopt minimum tillage and animal manure use, but equally like to adopt a variety of other intensification methods including inorganic fertilizer use (Ndiritu et al., 2014).

Although individual management of agricultural plots suggests a degree of empowerment and self-determination the potential gains to women may be attenuated if they are left to operate low quality and smaller plots on which only economically minor crops or those crops meant for household provisioning can be grown (Marenya et al., 2015). Plots are not distributed randomly to men and women (Doss, 2015). The Kenyan study noted above (Ndiritu et al., 2014) found that women are typically allocated smaller plots with lower soil fertility. Differential yields tend to reinforce soil variability, because intra-household decision-making processes prioritize resource and labour allocation to their best yielding fields (Ndiritu et al., 2014). This can create a self-

perpetuating cycle of continual soil-amendment investments in men-managed plots (Ndiritu et al., 2014). Mathenge and Smale (2013) also found that more fertilizer is applied to better soils and to the most lucrative cash crops. In other words, despite yield gaps it can become increasingly difficult for women to make the case in intra-household decision-making processes, particularly when they exhibit lack of jointness, for investments in N fertilizer on their plots. At the same time the downward spiral in profitability can make it ever more problematic to make own-account investments. Finally, there is tantalizing data on other trade-offs associated with the increased use of N fertilizers which requires more research. Men-controlled plots that are fertilized are weeded more frequently and this burden predominantly falls on women (Tittonell, Vanlauwe, de Ridder, & Giller, 2007).

High intra-household jointness and fertilizer N use

The 'gender gaps approach' to estimating potential productivity neglects the potential increases that could be achieved through programmes to promote equity in intra-household bargaining and cooperation. Many households display stronger jointness than in the examples just discussed, with both women and men involved in decision-making around farm management (Kassie et al., 2015; Marenya et al., 2015). It is often the case that plots are managed in different ways by the same household: some joint and some separate. In Kenya, for instance, a study showed that within MHH 45% of the plots are jointly managed by both women and men, and a further 17% are managed by women alone (Ndiritu et al., 2014). Despite this, there is little research on the ways in which co-management of plot affects decision-making around inorganic fertilizers, and whether co-management can be associated with an improved flow of benefits to women.

A study conducted in three districts in Mozambique examined the differential fertilizer application rates on plots managed individually by men, women or jointly in dual adult households (Marenya et al., 2015). It found that men manage the majority of plots: 62% of maize plots, 56% of fruit and vegetable plots and 71% of non-staple cash crops plots. Twice as much inorganic fertilizer is applied to maize plots managed by men than by women. Men also apply considerably more fertilizer to their other crops than do women. Fascinatingly, however, fertilizer use is highest on jointly managed maize and fruit and vegetable plots, and lower for non-staple cash crops than on individually managed fields – whether male or female managed. Jointly managed plots also exhibit higher incidences of soil and water conservation structures, and are more likely to have maize-legume intercropping, use of manure and improved agro-ecological practices more generally. The simulated effect of joint management was modest compared with plots individually managed by men but substantial (a 49% increase) for plots individually managed by women. Chirwa et al. (2011) similarly find in Malawi that women-managed plots are less likely to use fertilizer (subsidized and commercially procured) than male-managed plots in MHH. If, however, households are fully subsidized then fertilizer is applied to all plots, probably because subsidized fertilizer is intended for subsidence production.

Findings like these suggest that improving women's bargaining power under joint management of agricultural activities may be a strategy for strengthening equitable input use. At the same time, more information is needed on the degree to which women determine the use of benefits from jointly managed plots. After all, it is possible that women may not have a strong voice in how the benefits obtained from jointly managed plots are distributed (Marenya et al., 2015; see Sen, 1990). More nuanced studies exploring intra-household decision-making processes and expenditure decisions, in various household typologies, are needed. Without such studies it will remain difficult to understand the ways in which intra-household decision-making processes affect adoption decisions and the flow of benefits – including actual food and nutrition availability – which can be directly associated with fertilizer use (Ndiritu et al., 2014).

Research into how the risk preferences of women and men within the same household feed into intra-household decision-making processes suggests that a woman's *relative* bargaining power within MHH determines the extent to which her risk preferences condition a household's agricultural choices including with respect to fertilizer selection and application (Sheremenko & Magnan, 2015). A study conducted in Kenya (Sheremenko & Magnan, 2015) found that MHH have more income, credit, savings and land than FHH. In the study area farmers typically used diammonium phosphate (DAP) and urea with the former being more risky due to its higher cost and necessity

for careful timing of application. The study hypothesized that farmer attitudes to risk are likely to be more evident in relation to DAP. MHH used the most DAP and urea on their plots and this was linked to higher adoption of hybrid maize (75%) compared to FHH (50%). Male loss aversion strategies in MHH result in reducing DAP use but not urea. This suggests that loss-averse MHH households opt to use more affordable fertilizer to avoid higher losses in the event of a shock, but do not discontinue use altogether. Interestingly, more empowered but risk and loss-averse women *within* MHH opted to use less DAP and urea than disempowered women in MHH who appeared to have little choice in the matter. In FHH, where women are the only breadwinner and decision-maker, they are more risk and loss averse and less likely to purchase DAP than men in MHH or to use urea when shocks occurred (Sheremenko & Magnan, 2015.).

Towards gender-balanced fertilizer N use

The evidence presented in this paper shows that women and children in both high and low N use scenarios are more vulnerable to negative externalities of inorganic fertilizer N use. These vulnerabilities are wide ranging and surprising. Our case study showed that mortality and morbidity of infants born to poor rural Indian women appears to be negatively affected through their mother's work in rice paddy, where they absorb fertilizer-derived toxins. In Lake Victoria, excessive N loading as a result of poor land management is transforming the ecology of the lake. This in turn is reconfiguring the social ecology of artisanal fisher societies, contributing to ever higher risks of HIV transmission. A more diffuse literature suggests, in the third case study, that women in selected low N use societies are not averse per se to applying inorganic N fertilizer to staple or cash crops. However, they are subject to a range of weighty gender-based constraints which may make it more difficult for them to do so than men, and to secure benefits commensurate with their expenditure. The relative jointness of intra-household decision-making processes may determine the ability of women to deploy their agency and make the case for increasing inorganic N applications to plots under their individual and joint management.

In the introduction, we outlined interrelated two cases for investing in women (Doss, 2015). The first suggests that women are increasingly important in agricultural production but have been neglected in most development initiatives. The returns to targeting women farmers for best practice N use should, therefore, be high and result in increased aggregate production and improve women's income. The second case argues that since women are frequently primary caregivers they are instrumental in securing improved health for all family members. Taken together, they make the case that the social returns on agricultural investments are higher when targeted to women. In this paper, we studied these two scenarios through an N fertilizer lens. The findings show that research is sparse and scattered and is not yet conclusive on these two points, particularly the former.

Intra-household decision-making

The evidence in this paper tantalizingly suggests that *existing* food availability, access and nutritional adequacy gaps in low N use settings could be narrowed by improving the equity of intra-household bargaining processes in relation to the benefits from fertilizer application as well as improved intra-household food distribution. If N fertilizer is to be preferentially applied to cash crops, this only makes sense in terms of food equity if a healthy and diverse food basket can be purchased from the market, and if it is indeed purchased and consumed equitably by all household members.

Indicative findings from recent agronomic research cited in this paper coalesce to suggest in that some low N use farming systems in SSA gender inequalities in intra-household decision-making around selection and use of N fertilizers on women, men and jointly managed plots appear to create production differentials. There is limited evidence that jointly managed plots receive more fertilizer and are subject to a wider range of interventions which in turn are likely to improve N uptake.

However, the equity of benefit distribution from crops produced on plots under different management scenarios has not been researched thoroughly. This is partly because research to date has been insufficiently multi-disciplinary. Opportunities to probe deeper by closing the 'hoe to fork' circle have been missed. Much of the research cited in this paper has been prepared by agronomists. Theoretical and empirical input from specialists in household bargaining models, including game theory, ideally on the same research projects, is needed to complement and deepen work by agronomists. Some scientists cited, like

Sheremenko and Magnan (2015) have disaggregated intra-household decision-making sufficiently to show that women in MHH either follow their husband's directives on fertilizer use, or act more or less independently. However, a clear understanding of how women develop and direct their agency in particular cultural contexts and within various household typologies remains to emerge in relation to decision-making around selection and use of inorganic N. There is some evidence that women may be more risk-averse (due to their primary caregiver role) and thus decline to use N fertilizer under certain conditions, but so far research into how women and men in different household typologies understand and weight risk in relation to N fertilizer use is scanty. Assumptions about the relative risk-averseness of rural women and men producers in specific scenarios require unpicking and testing.

Systemic research is needed on the rates of inorganic N use on women-managed, men-managed and jointly managed plots, and any other management configurations relevant in the local context. More evidence is needed on the degree to which N application differs by management type, the rationale (from the plotholder's point of view) for these differences and how differential application affects plot productivity by manager and by crop. At the same time, the distribution of benefits from differently managed plots needs to be examined carefully. There are no grounds for assuming a linear relationship between the gender of a plot manager and that person's ability to secure benefits. Nor can it be assumed that jointly managed plots produce joint benefits. An important research hypothesis is that gender inequalities in intra-household decision-making may result in the direct export of the benefits of N outside the household into the market economy, with a failure to return these benefits to all household members, including children, in the form of improved food and nutrition security. This hypothesis needs considerable testing. It is important to do so because research and policy assumptions that investments aiming to restructure smallholder systems towards market-orientated production will result in improved food and nutrition outcomes in producing households are widely held. However, there are no grounds – based on findings from research conducted over many years – to assume that monies made from selling cash crops will be reinvested in improving food and nutrition security outcomes for all household members.

Another area of research could include examining the claims of household methodologies (HHM) to increase the equity of intra-household processes and to link these to a range of enhanced development outcomes (Farnworth & Munachonga, 2010; Farnworth & Shiferaw, 2012). These include improved systemic farm level planning across all plots of land held by a particular household thus contributing to strengthened production and productivity. HHM have been developed by a range of development sectors over the past decade including SIDA, USAID, IFAD, Oxfam-Novib and Send a Cow, among others. A generic range of steps have been brought together by IFAD in a manual, and indicative case studies produced (https://www.ifad.org/topic/household_methodologies/overview). Increasingly, HHM are being used as an entry point for introducing new adaptation and mitigation technologies. They could be one way of promoting gender-equitable adoption of the 4Rs to achieve balanced NUE and to move towards improved household level food and nutrition security.

Alternative sources of N

Strengthening biological fixation of N through legumes, recycling and use of organic N sources such as manures, can help close the N cycle, reduce leakiness and increase NUE (Lassaletta et al., 2014; Sutton et al., 2013). Whilst this paper has concentrated on the gendered availability and use of inorganic N fertilizer, ecological intensification (EI) approaches include a number of alternatives or partial surrogates (Bommarco, Kleijn, & Potts, 2013). There are advantages and disadvantages with respect to women's involvement and benefit distribution from these more ecologically based approaches. For instance, whilst EIs reduce reliance upon (expensive) inorganic fertilizer, they are often dependent upon resources such as animal manure and crop residues which women may find difficult to access in sufficient quantities, and they can also involve heavier workloads which are predominantly absorbed by women (Halbrendt et al., 2014). More research on what alternatives to business-as-usual agricultural intensification actually entail in terms of workloads for women and the equity of benefit distribution is required.

Gender-smart policy

Achieving balanced N use requires improved gender-smart fertilizer use legislation in high and low N use

contexts. However, as long as the majority of policy-makers and planners remain frozen into a conceptual lock-in which denies the significance of gender to the agricultural sector (Farnworth & Colverson, 2015), the pathways towards technically balanced and socially balanced fertilizer N use and improved NUE will be littered with systematically embedded obstacles.

Policy-makers require empirically robust data on the implications of high and low NUE for gender and social equity in forms which promote ease of decision-making and the development of do-able policy and strategies. It is critically important that they are able to understand the causal links between levels of use and the potential for causing harm to health and food security. This will facilitate the 'gender-readiness' of the rural advisory services to develop appropriate strategies to reach women in different household typologies and help them exercise their agency. Attempts to work closely with input suppliers of inorganic N to help them develop market strategies tailored to women's needs will be improved.

Conclusion

The paper shows that the negative externalities of imbalanced inorganic N use in high- and low-use scenarios impact most strongly on women and children. More balanced use of N could deliver better gender outcomes in relation to health and livelihoods as highlighted in the case studies. Gender-equitable NUE strategies will help to integrate and assure gender and social equity co-benefits in LED at local scales. However, change will ultimately be reliant on significant shifts in locationally specific deep structures informing gender and social norms.

It is possible that gender-equitable technical strategies for achieving more balanced use of N will increase the likelihood of attaining macro-level reductions in GHG emissions provided that they pay attention to securing equity in intra-household decision-making. This is because NUE may be improved across all plots, regardless of the gender of the plot manager, throughout the farm system.

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