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Agricultural inputs and nutrition in South Asia

Bhavani Shankar[a,*], Nigel Poole[a], Frances A. Bird[b]

[a] SOAS, University of London, 10 Thornhaugh Street, Russell Square, London WC1H 0XG, United Kingdom
[b] London School of Hygiene & Tropical Medicine, Keppel Street, London WC1E 7HT, United Kingdom

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ABSTRACT

There are a number of potential pathways leading from agricultural input decisions to nutrition outcomes of farm households. These have special resonance in less developed areas of South Asia given widespread undernutrition problems, market failures and restricted access to land and other key assets and inputs, as well as ongoing debates around the implications that the green revolution has held for nutritional outcomes. A number of initiatives, including the Leveraging Agriculture for Nutrition in South Asia (LANSA) project have been undertaking research that addresses these linkages. The objectives of this paper are to systematically review the recent evidence on linkages between agricultural inputs and diet and nutrition outcomes of farm households in South Asia, place relevant LANSA research within the context of this review, and draw implications for policy, practice and the future research agenda. We focus on land and livestock assets and the set of productivity enhancing inputs in the form of irrigation, seed and agrochemicals. We report on a systematic review of recent evidence based on observational data on the links between these agricultural inputs and assets and diet and nutrition outcomes of farm households in India, Pakistan, Bangladesh, Afghanistan and Nepal. We find that the literature has slowly but steadily grown since previous reviews conducted in the early 2010s, but that there is still a long way to go. Review results suggest that while there is no indication that land ownership or size by themselves have clear associations with farm household dietary or nutrition outcomes, land productivity is more clearly associated with improved outcomes. Yet the literature linking specific inputs such as improved seeds or irrigation with nutrition remains very thin. The literature appears strongest for the case of links between livestock keeping and dietary and nutrition outcomes. This is particularly the case with animals reared for milk, with the evidence indicating milch animal ownership improves household milk intakes and thereby influences the growth of children. Priorities for future research include the formulation and testing of more specific hypotheses relating to input-nutrition linkages and more strenuous efforts to improve causal identification in this literature.

1. Introduction

The last few years have witnessed a significant expansion in research on agriculture-nutrition linkages in low and middle income countries. A high proportion of this research has examined such linkages at the farm household level, reflecting the frequently low welfare status of this important constituency as well as market failures that make production and consumption non-separable. The literature on the links between agricultural *output* choices (*e.g.* milk production) or production diversity on farm household diets and nutrition is especially rich, and has recently been rigorously reviewed (Jones, 2017; Sibhatu and Qaim, 2018). However the research base on links from agricultural asset and input (*e.g.* land and livestock assets, irrigation, seed varieties) decisions and constraints and farm household diet and nutrition outcomes is more scattered and incomplete. There are important pathways from key agricultural inputs and assets to diet and nutrition outcomes of farm households (including their role in the determining or being co-determined with production diversity).

Understanding these pathways and influences is of particular importance to South Asia, where breeding of high yielding varieties of crops, especially cereals, accompanied by policies promoting the use of fertilizers and pesticides, has revolutionised production since the 1970s (Pingali, 2012; Hazell, 2009). These investments and policies focused on the green revolution package of inputs have been instrumental in raising productivity of South Asian staples, alleviating poverty, boosting food security and reducing hunger. With income increases,

* Corresponding author.
E-mail addresses: b.shankar@soas.ac.uk (B. Shankar), n.poole@soas.ac.uk (N. Poole), f.bird@lshtm.ac.uk (F.A. Bird).

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populations in these countries are demanding more diverse diets. However, it has been argued that the agricultural policies and the input packages they have promoted have mostly remained staple cereal-focused and ill-suited to promoting diversified production to meet demand (Pingali, 2015; Shankar, 2017; Shankar et al., 2017). That said, in spite of much speculation in the literature, robust evidence on actual diet and nutrition outcomes of enhanced use of green revolution inputs has been slow to emerge. Whilst these concerns are relevant at the population level, in this paper our predominant focus is on the subpopulation of farm households. For this constituency, there are not only valid questions around whether higher endowments of agricultural assets or the use of productivity-enhancing 'modern' inputs sufficiently encourages dietary diversity and nutrition outcomes, but also other nutrition implications such as those arising from animal faeces or pesticide exposure become particularly relevant.

The LANSA project has carried out a set of studies examining some of these linkages, including studies on livestock asset ownership and anemia outcomes, and irrigation and dietary diversity. The objectives of this paper are to (a) systematically review the recent evidence on linkages between agricultural inputs and diet and nutrition outcomes of farm households in South Asia, (b) place relevant LANSA research within the context of this review, (c) draw emerging policy and practice implications from the review and synthesis, and (d) identify major gaps in the evidence and indicate priority areas for future research. At the core of this paper is a systematic review of recent evidence on the links between agricultural inputs and diet and nutrition outcomes of farm households in India, Pakistan, Bangladesh, Afghanistan and Nepal. This review provides the frame for a contextual synthesis of LANSA work in this area and a discussion of policy and practice implications and research priorities for the future.

Our scope here encompasses the four core LANSA study countries – India, Pakistan, Bangladesh and Afghanistan. We also include Nepal as a LANSA 'outer ring' country that has been the setting for other large projects linking agriculture and nutrition. Of this set, a high proportion of the available evidence derives from studies set in India and Bangladesh. Systematic reviews of broad agriculture-nutrition linkages in these two countries covering literature up to the early 2010s have already been published in Kadiyala et al. (2014) for India and Yosef et al. (2015) for Bangladesh. Therefore our review is confined to the most recent literature, from 2012 onwards. Our coverage of input and agricultural asset categories is not comprehensive. In order to keep the review task bounded and not excessively diffuse, we limit our coverage of input categories. Land and livestock access/ownership are included, not only because of the well-known constraints to access to these assets in the rural South Asia context, but also because of their multiple pathways to improved nutrition, discussed below. The package of green revolution inputs – irrigation, (improved) seeds and agrochemicals – is of central interest to the region as discussed above, and is covered here. Thus our focus is broadly around the fundamental agricultural assets, land and livestock, and the variable inputs that enhance the productivity of those assets. This focus is not to deny the importance of links between other input categories and nutrition (labour is of particular importance, and some key gender aspects to labour-nutrition linkages is reviewed elsewhere in this issue (Rao et al., 2018)). It should also be noted that we confine our attention to studies based on observational data – studies using intervention data are covered in Bird et al. (2018) in this issue.

The paper continues with a short section describing the key pathways from these input categories to nutrition outcomes. Within this section we also briefly review the findings of the two previous reviews, from India and Bangladesh respectively, with respect to the input categories under investigation here. Subsequently, we describe the systematic review methodology and provide a narrative review of the results. Discussion of pertinent LANSA research is woven into the narrative review discussion. The final section concludes and outlines priorities for policy, practice and future research.

1.1. Pathways from input categories to nutrition

1.1.1. Pathways

Where markets function smoothly, production and consumption decisions of farm households are completely separable (Singh et al., 1986). In such cases, the relevant pathway from all the input categories to diets and nutrition of farm households is the self-evident one – that their increased use boosts agricultural production and farm incomes (via market participation), thereby increasing the demand for dietary diversity and improved nutrition outcomes. However, market failures are rife in rural South Asia, and subsistence production is widespread as a result of high transactions costs in accessing markets (Taylor and Adelman, 2003). In such cases, on-farm production becomes directly relevant to what is consumed, and input categories can affect diets via their influence on the range and quantity of outputs that are produced on farm. Below, we highlight some particular cases of influences from inputs to nutrition beyond the standard pathway that goes from more remunerative production to improved farm incomes and improved dietary diversity.

The two agricultural asset categories we consider, land and livestock, have multiple pathways towards nutrition. Land, of course, is a prerequisite to most forms of agriculture, and therefore embeds several pathways to diets and nutrition depending on quality characteristics and other agricultural decision making, including the use of other inputs. Access to livestock assets promotes the availability of animal source foods amongst farming households where markets are incomplete, and studies set in Africa have found strong associations with nutrition outcomes, including child linear growth (Rawlins et al., 2014; Headey and Hirvonen, 2015). There is also a pathway to nutrition defined by the interaction between gender and the ownership of land and livestock assets. Increased land ownership by women (compared to men) has been associated with increased empowerment of women, which in turn has been linked to improved child nutrition (Allendorf, 2007). A similar relationship has been previously reported for female ownership of livestock and child nutrition outcomes (Jin and Iannotti, 2014). Finally, livestock are kept in close proximity to human living areas in many parts of the developing world. Increasing evidence is emerging that contact with animal faeces may increase exposure to enteric pathogens, contributing to subclinical environmental enteropathy disorders that influence child stunting (Ngure et al., 2014). Data on the impact of the promotion of livestock production on the prevalence of other zoonoses and thence nutrition is scarce (Leroy and Frongillo (2007), even though zoonotic pathogens are known to have been responsible historically for many human disease threats and recent new sources of infection (McDaniel et al., 2014), thus constituting an intermediate factor determining nutrition outcomes.

Irrigation may provide incentives to substitute food crops with cash crops, or may incentivise focus on a narrow range of high-value staples (Domènech, 2015). But irrigation may also enable the addition of nutritionally important foods to the farm household's production portfolio. For example, irrigation is essential for most vegetable cultivation and some fruit and nut tree crops. Fodder production supported by irrigation can improve livestock productivity and incentives for engaging in livestock production. Whilst production changes enabled by irrigation will generally act in the direction of boosting dietary diversity of farm households via the income pathway, the impact on dietary diversity via the own consumption pathway will vary by empirical setting. There may also be an impact on diets via a variety of other situation-specific pathways – for example, the emergence of irrigation technologies for dry-season rice production in Bangladesh has had negative impacts on the local inland fishery and floodplain fish that have been traditionally important in local diets (Shankar et al., 2005). Irrigation may provide a relatively safe source of drinking water in some parts of the world, and also constitute a source of water-borne infectious and parasitic diseases with attendant implications for nutrition.

Often, as in the Green Revolution, pesticides, fertilizers and new seeds constitute a synergistic package of inputs. As with the case of irrigation, the main pathway from these inputs to nutrition is likely to be through their influences on productivity and income. Again, as in the case of irrigation, the use of these inputs may be associated with changes in the relative returns to particular enterprises and thereby with changes to the production mix. Where there is a significant degree of own-consumption, this has implications for dietary diversity and nutrition. Devising fertilizer application strategies or plant breeding approaches (biofortification) to increase concentrations or bioavailability of minerals in crops constitute further pathways from fertilizers and seeds to human nutrition. Seed varietal development that shortens growing seasons can help address temporal nutritional deficits. On the other hand, exposure to pesticide, long associated with multiple negative health outcomes, has also been linked to diabetes (Evangelou et al., 2016).

Of course, decisions about a particular input use can also trigger nutrition-relevant changes to other inputs. In particular, changes in agricultural asset ownership and input use can also have implications for the time-use of women, with attendant implications for child care and nutrition (Johnston et al., 2018). The links between agricultural input changes, productivity enhancements and nutrition outcomes are generally influenced by intra-household decision making, including intra-household labour allocation (*eg.* labour demands on women arising from input use change) and intra-household consumption allocation (*eg.* gender-varying allocation of additional consumption arising from productivity enhancement).

1.1.2. Previous reviews

The systematic review conducted by Kadiyala et al. (2014) found little high-quality evidence on agriculture-nutrition interactions for India: 'Studies with strong causal identification are almost nonexistent' (p. 51). However, one important finding that emerged from studies was the evidence that livestock ownership was an important determinant of the consumption of livestock products. They commented that access to land and irrigation to boost productivity in general and livestock production in particular are key issues for Indian agriculture but that there is not yet a compelling evidence base for positive impacts of increased output on the nutritional status of vulnerable groups, nor of nutritional impacts – positive or negative – attributable to the health hazards of livestock and irrigation. Similarly, concerns about agricultural inputs such as agrochemicals were subsumed within discussion about productivity improvements. Potential nutritional hazards from toxins were subsumed with general health impacts which likely swamp the effects of inhalation and absorption through misapplication of agrochemicals, and ingestion directly or through the food system.

Yosef et al. (2015) review of evidence for agriculture-nutrition linkages in Bangladesh similarly found the evidence base found to be weak. The studies examining exposure to agrochemicals found low levels of pesticides in breast milk but high levels of insecticides such as DDT, compared with other countries, and high levels of cadmium probably derived from rice. Little evidence was recorded on the modes of exposure to, and effects of environmental and agrochemical hazards on, nutrition and health of vulnerable groups, in particular infants and young children.

2. Methods

This systematic review follows the PRISMA-P Checklist (Preferred Reporting Items for Systematic review and Meta-Analysis Protocols).

2.1. Screening and study selection

The objective of this review was to identify *observational studies* set in South Asia that used quantitative or qualitative methods to link farm or household level decisions regarding agricultural inputs with their nutritional status. The search concepts and related search terms were developed using previous reviews such as Ruel et al. (2017). As stated in Table 1, the three main search concepts were 'South Asia', 'Agricultural inputs' and 'Nutritional outcomes'.

Six literature databases were chosen: Web of Science, Scopus, PubMed, CAB Abstracts, AGRIS and EconLit. We focused our literature search on journal articles published in English between 2012 and February 2018. The search was conducted in February 2018 and included only published peer-reviewed studies; this included working papers and PhD theses that showed evidence of being peer-reviewed. Non-peer reviewed grey literature and review articles were not included. Any articles written under the LANSA research partnership were excluded as part of the systematic review but are integrated into discussion of review results. Hand searches of review paper citation lists and research from the Nutrition Innovation Lab were searched for additional papers that met our selection criteria. It is important to note that only observational studies were included, given that intervention studies are reviewed elsewhere in this series. Also, only studies at the

Table 1
Search concepts and key terms.[a]

Concept	Search terms
South Asian Region	South Asia, Asia, Pakistan, India, Afghanistan, Bangladesh, Nepal
Agricultural input	irrigation, fertilizer/fertilizer, pesticide, agrochemicals/agrichemicals, land, animal, livestock (cow, sheep, chicken, buffalo, goat, poultry, pig, yak, camel, donkey, horse, rabbit), faeces/feces, biofortification, seed/crop varieties/cultivars
Nutritional outcomes	nutrition, "nutritional status", "nutritional outcomes", malnutrition, "nutrition security", "food security", hunger, "diet diversity", "diet quality", "diet/nutrient adequacy", BMI, wasting/ed, underweight, micronutrient, stunting/ed, anthropometry/ic, anaemia/anemia, iron, zinc, "Vitamin A"

[a] Animal faeces was added to the search terms in order to improve the ability of the search to pick up research on the hypothesised pathway linking exposure to livestock faeces and negative nutrition outcomes. Likewise, biofortification was explicitly included in order to pick up that specific pathway from seeds to nutrition.

Table 2
Quality assessment criteria.

#	Quality criteria	Description
1	Study design	Present the key elements of the study design, including location, target group and size of survey
2	Exposure variables	Agricultural inputs at farm and household level. Details of data collection methods. Details of comparison group.
3	Statistical methods	Describe all statistical methods
4	Nutrition outcomes	Nutritional outcomes: relating to anthropometric measurements or biochemical indicators of micronutrient status, and intermediate outcomes including dietary diversity, intakes of key food groups, nutrient availability/intake (protein, iron, zinc, vitamin A, nutrient adequacy ratios). Details of data collection methods.

farm household level were included, excluding studies at higher levels of aggregation, e.g. district level studies.

2.2. Data extraction and quality assessment

Information on the study location, design, target population, agricultural input, study length, measurements of methods and outcomes were extracted for each of the final included studies.

The final studies were assessed on the 4 quality criteria that were derived from the STROBE quality checklist (Table 2), and only studies that met all the criteria were included in the study.

2.3. Data synthesis

The exposure and outcome data were too diverse to synthesize quantitatively, therefore the main findings are reported descriptively under sub-headings for the various agricultural input types such as irrigation, fertilizer and livestock ownership. Within these broad sub-headings, we integrate and compare the findings of the relevant LANSA commissioned research.

3. Results

Our rigorous search returned 7349 studies. After screening the studies against the inclusion and exclusion criteria, there was a final total of 13 studies (Fig. 1). A summary of the included studies is provided in Table A1 in the appendix.

3.1. Land

Six out of the final list of fourteen identified papers discussed or included information on the relationship between land ownership/access/use and nutrition outcomes. Five of the six papers used statistical methods on quantitative data, while one (Pritchard et al., 2017) was a mixed methods study in two Indian communities that did not report statistical tests. All five papers reporting results of statistical tests used cross-sectional data in the estimation of regressions. Also, all five studies aimed to analyse multiple ‘drivers’ of nutrition outcomes, and did not focus only on the land-nutrition relationship. Accordingly, no special effort was made in these papers to establish causal relationships, making the estimates prone to confounding and selectivity biases. This is likely to be a particular issue with expensive agricultural assets such as land, given their widespread use as stores of wealth, particularly in South Asia. More prosperous households are likely to hold more land as well as have better nutrition outcomes, and so it is difficult to make causal claims on the basis of standard regressions. Most of the studies control for a range of other wealth and income indicators, thereby reducing confounding. Nevertheless, the ‘selection on observables’ assumption underlying any causal claims from such estimation is a very strong one. Therefore the studies are only able to discuss associations rather than causal ‘impacts’.

A broad finding that emerges from these papers is that neither land ownership by itself, nor land size, seem to have strong or consistent correlations with dietary diversity and nutrition outcomes once wealth is controlled for. Harris-Fry et al. (2015) find in their sample in Bangladesh that whilst land ownership reduces food insecurity, no significant association exists between land ownership and women’s dietary diversity when a range of other covariates is controlled for. LANSA research reported for Bangladesh in Hossain et al. (2016) finds land ownership to actually have a negative, albeit very small, correlation with dietary diversity, controlling for income, other assets and production diversity. Shively and Sunantsanuk (2015) find no statistically significant relationship between land size and child height for age outcomes in Nepal. Mulmi et al. (2017) and Dorsey et al. (2018) also analyse data from Nepal, albeit without any explicit focus on land ownership or size. Mulmi et al. (2017) find that land owned has a positive association with odds of being above threshold dietary diversity only for oldest age group of children that they consider (18–23 months), while being insignificant for younger groups. Dorsey et al. (2018) find no relationship between any agricultural variables, including land owned, and stunting odds in the multiple logistic regression that they estimate.

Apart from the difficulties in deducing causality from cross-sectional regressions, an additional challenge with inferring much about the relationship between land endowments and nutrition outcomes from this literature is that each study institutes different controls along the land-nutrition pathway. For example, some may control for production diversity in addition to land while others may not. An example of this is that whilst Bhagowalia et al. (2012) using India Human Development Survey (IHDS) data for 2005 find no significant association between land size and household dietary diversity in India, LANSA research reported in Viswanathan et al. (2015) using the same dataset reports a positive association between cultivated area and household dietary diversity.

The findings of the mixed-methods study by Pritchard et al. (2017) in two communities in India are consistent with the notion that the relationship between agricultural land and nutrition in South Asia is complex and not amenable to simple generalization. They discuss that, as land holdings have sub-divided and shrunk and migration and the non-farm economy have grown in India, the link between landholding and consumption and nutrition outcomes has become subject to great local diversity and mediation by aspects such as non-farm livelihood opportunities and local gender norms. In their study sites they find that milk consumption in particular is substantially lower amongst the landless, and their qualitative research suggests that the ability of those with land to grow fodder for their livestock is a key factor in this.

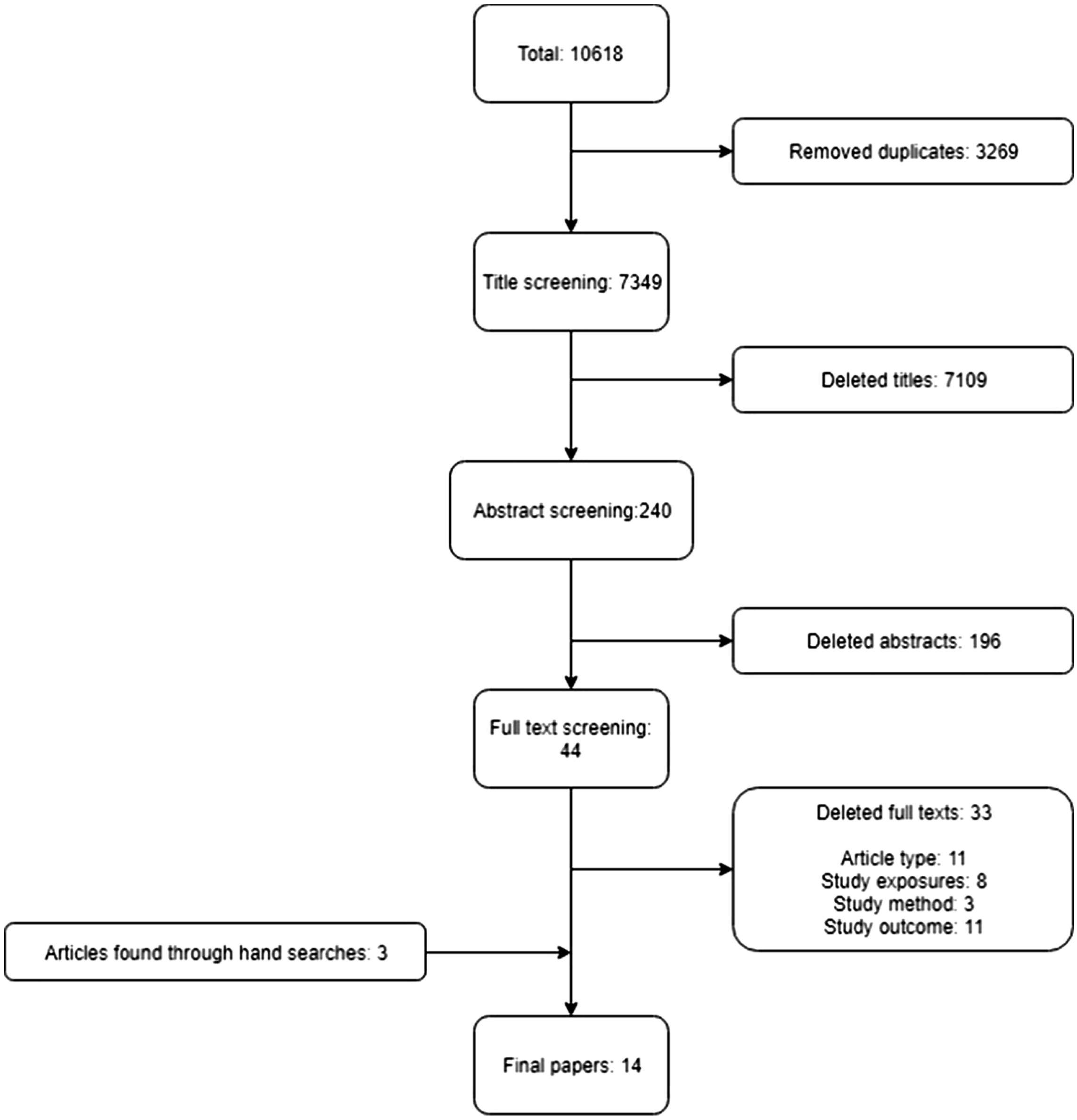

Fig. 1. Flow chart following the screening process of the rigorous review.

3.2. Irrigation, fertilizer, seed

One interpretation of the above discussion is that agricultural land ownership and size may by themselves not be clearly linked with nutrition outcomes in South Asia because it is the features of the asset, and the complementary inputs applied, manifested in its productivity that matters for nutrition outcomes. As such, translation of asset use change into productivity enhancement is shaped by both technology adoption as well as market participation, the lack of which can limit the productivity, and ultimately, nutritional impacts of increased land or livestock holdings.

In the Shively and Sunantsanuk (2015) study, although land size is not associated with child height for age (HAZ) as discussed above, agricultural yield is reported to have a statistically significant positive relationship with HAZ for children over 24 months. Dorsey et al. (2018) find that children in the higher agriculture potential Terai (plains) from households not purchasing fertilizer or seed were more likely to be stunted than children from households engaging in purchases. However, this relationship between fertilizer and seed purchase and stunting is not found in the low potential hills and mountainous regions where agriculture is a less prominent feature of livelihoods. Bhagowalia et al. (2012) find that irrigation is positively related to household dietary diversity for very small farms in India, even though land size and dietary diversity are not significantly correlated in general.

The review identified one paper reporting a simulation study into biofortified seed. Vitamin A Deficiency (VAD) is one of the prevalent micronutrient deficiencies in Asia. Using existing data sets from Bangladesh, Indonesia, and the Philippines, De Moura et al. (2016)

conducted a study to simulate the increase in vitamin A intake if rice biofortified with beta-carotene were consumed instead of regular rice. For Bangladesh, substitution at high concentrations decreased the prevalence of VAD from 93% at baseline to 20% and 13% among children and women respectively.

Overall, the recent literature on the nutrition implications of productivity enhancing inputs – irrigation, fertilizer and seed – is thin, with the available evidence not attempting to establish causal linkages and stopping short of investigating specific pathways through which any relationships might operate. LANSA research by Kawsary et al. (2018) contributes to filling this lacuna by investigating the irrigation-dietary diversity relationship amongst farm households in Afghanistan. This study uses data from the 2013–14 round of the Afghanistan Living Conditions Survey. The availability of information on the sourcing of various foods allows investigation of specific pathways through which any relationship between irrigation and dietary diversity might operate. As discussed before, a difficulty with many studies in the literature reviewed here is the selectivity bias arising from the use of cross-sectional data. The Kawsary et al. (2018) study attempts to address this selectivity by using instrumental variables methods. Results show that possession of irrigated land and garden plots are positively associated with household dietary diversity. The study finds support for both key pathways from irrigation to dietary diversity. Availability of irrigation is positively correlated with diversity of food intakes from own production. At the same time, irrigated garden plots are associated with more diverse foods purchased at the market.

3.3. Pesticide

On agrochemical use and health and nutrition impacts, Swaminathan and Thangavel (2015) investigate an apparent relationship between increasing rates of diabetes and farmers' use of organophosphate pesticides around the city of Madurai, India, finding a moderate association between pesticide exposure and diabetes. A study by Paudel et al. (2012) in mid-west Nepal used a community-based case control design to identify risk factors associated with child stunting. They found a relationship between exposure of mothers and children to pesticides through vegetable gardening and stunting. Exposure to pesticides was significantly higher among stunted children compared to non-stunted. However, given the small sample size, lack of adequate controls and non-explication of a recognized pathway from pesticide exposure to stunting, the extent to which firm conclusions can be drawn from this study is unclear.

3.4. Livestock

In the case of livestock assets, the evidence on associations with nutrition outcomes appears most compelling for the specific pathway whereby ownership of milch animals raises household milk consumption, which in turn impacts linear growth in children. Bageant et al. (2016) examine and find support for these hypotheses using multiple rounds of the Nepal Living Standards Survey data. Their relatively strong study design uses panel data for the livestock ownership – milk consumption link, and is thus able to control selection bias to some extent. They find strong associations between milk production and consumption and between milk consumption and child (0–5 years) height for age in Nepal, with the strongest associations holding for buffaloes. Similarly, Bhagowalia et al. (2012) in their cross-sectional regressions find a strong relationship between ownership of cows and buffaloes and household milk budget share in India. In another cross-sectional regression study, Jumrani and Birthal (2015) find ownership of large ruminants (cows and buffaloes) in India to be negatively associated with underweight amongst children aged 2–5 years.

Exploring the ‘gendered’ pathway, Jumrani and Birthal (2015) find that livestock care by women is associated with lower probability of stunting, wasting as well as underweight for children aged 0–2 years (although not for older children). They argue that livestock assets, compared to land, can be acquired with relatively low investment, are less bound by traditional property rights, and that their acquisition by women can boost their intra-household bargaining power, resulting in greater investments in child nutrition.

LANSA research in Afghanistan (Flores-Martinez et al., 2016) examines a specific pathway hitherto unexamined in household-level studies in the region – one that leads from livestock keeping to red meat intake (from own consumption) to anemia. Ownership of sheep and goats for household meat production is widespread in Afghanistan. Meat from these animals can be a valuable source of bioavailable heme iron, and can also boost the bioavailability of non-heme iron in the diet. This study uses information from two datasets to explore linkages between livestock keeping and anemia outcomes. First, analysis of the 2010/11 Afghanistan Multiple Indicator Cluster Survey data reveals that sheep ownership decreased odds of anemia amongst adult women, after adjusting for wealth and other confounders. Regressions estimated using the 2011/12 Afghanistan National Risk and Vulnerability Assessment household survey data then show that sheep ownership is associated with increased odds of a household consuming mutton, the frequency of mutton consumption and the quantity consumed. Taken together, these results are suggestive of household sheep rearing in Afghanistan contributing to reduced prevalence of anemia, which is a major nutritional problem in the region.

Estimation of less specific livestock-nutrition linkages in the literature seems to reveal less clear results, especially with cross-sectional designs, aggregate representations of livestock assets, and without control for selectivity. Shively and Sunantsanuk (2015) do not find a significant relationship between household production of animal protein (dummy variable coded as 1 if the household produces any of eggs and/or milk and/or meat) and HAZ in Nepal for children younger than 24 months, but do find a positive relationship for older children. Harris-Fry et al. (2015) find that livestock ownership (dummy coded as 1 if any livestock owned) lowers the risk of severe food insecurity, but is not associated with women’s dietary diversity score.

A recent literature that has emerged subsequent to the Kadiyala et al. (2014) and Yosef et al. (2015) reviews examines the pathway from livestock keeping to negative effects on child growth via environmental enteropathy (EE). Headey et al. (2017) report on a multi-country cross-sectional study exploring links between livestock ownership, animal faeces prevalence in the compound, and child nutrition outcomes. Their findings for Bangladesh indicate that livestock ownership is positively associated with the presence of animal faeces in the compound, which in turn is negatively associated with HAZ of children aged 6–24 months. George et al. (2015) also examine the case of Bangladeshi children in a small cohort study of 219 children aged < 30 months. Their study additionally measures faecal markers of EE based on stool samples, and they report a significant relationship between corralling of animals in child sleeping quarters and elevated EE scores and higher odds of stunting. Contrary to these Bangladesh studies, however, a null result is reported by Schmidt et al. (2016). Their cohort study of 2739 children in Odisha, India, additionally measures the presence of vectors for pathogens in these settings in the form of synanthropic flies. None of their measures of exposure, including cow ownership and presence of a cowshed in or near the household compound, is found to be linked to increased fly prevalence, diarrhea incidence or growth for children <

5 years of age. Thus this small literature currently shows mixed results, although it is expected to expand substantially in coming years.

4. Discussion and conclusion

Our systematic review of linkages between agricultural asset ownership and input use and nutrition outcomes amongst farm households in South Asia has shown that the literature has slowly but steadily grown since the reviews of Kadiyala et al. (2014) and Yosef et al. (2015), contributing to new insight with programming and policy implications, but that there is still a long way to go.

Although land scarcity is a characteristic feature of South Asian agriculture, and land holding is considered to correlate well with wealth in rural areas of the region, there is little indication from the available evidence that land ownership and size by themselves have strong or consistent relationships with dietary diversity or other nutrition outcomes of farm households, once wealth is controlled for. However, unsurprisingly, there is better evidence that improved productivity of land correlates positively with farm household nutrition outcomes, although there is little evidence yet that intensifying agriculture in marginal (and unirrigated) areas will lead to improved nutrition outcomes.

Underlying improved land productivity is the use of irrigation, fertilizer and improved seed varieties. Although these productivity enhancing inputs would typically be expected to broadly improve the nutrition of farm households, there are potentially important and interesting mechanisms and pathways to such impact that research could shed light on. However, our review highlights a continuing paucity of such research in South Asia. For example, no research was turned up on (non-biofortified) seed varieties and farm household nutrition outcomes, despite the long and successful history of plant breeding, particularly for staples, in the region. LANSA research on irrigation in Afghanistan is an exception, illustrating the multiple land-use types (cropping and garden plots) and food sourcing patterns (own-consumption and market purchase) through which irrigation availability improves dietary diversity.

In some areas of the literature, the evidence base for Africa appears well advanced compared to that for South Asia. An example of this is the evidence on the nutrition implications of biofortified seed varietal development. Our review as discussed above found only one study on biofortified varieties that met our inclusion criteria, a simulation study (De Moura et al., 2016). Although there have been important developments in the release of biofortified varieties in South Asia, such as for iron pearl millet (Andersson et al., 2017), the recent literature on biofortification in a range of African countries is considerably richer. Doubtless this reflects a range of factors such as donor priorities and national regulatory processes that dictate the length of time for which biofortified varieties have been available. As biofortification efforts gather pace in South Asia, it is important that a robust research agenda develops around the *ex-post* evaluation of nutritional impacts.

The literature we have reviewed appears strongest for the case of links between livestock keeping and dietary and nutrition outcomes. This is particularly the case with animals reared for milk, with the evidence indicating milch animal ownership improves household milk intakes and thereby influences the growth of children. The 'milk' pathway has plausibility in our context because of the importance of milk in the otherwise cereal-dense diets of many South Asian populations, and also due to pervasive market failures in rural areas especially for perishable products such as milk, making own-consumption a common feature. A striking example of this comes from Afghanistan. Our processing for the LANSA project of data from the National Risk and Vulnerability Assessment survey of Afghanistan shows that, whilst high proportions of cereals and pulses are sourced from the market, almost three times as many households sourced milk from their own animals than households procuring from the market. Some progress has also been made since 2012 in generating evidence relating to other livestock-nutrition pathways for which little or no evidence was recorded in the Kadiyala et al. (2014) and Yosef et al. (2015) reviews. LANSA research suggests a link between small ruminant rearing and anemia for the case of Afghanistan. The connection between animal keeping in close proximity to household quarters, so typical in the region, and resultant exposure to animal faeces and negative implications for child growth arising from environmental enteropathy is starting to receive due attention even if the evidence appears mixed at present.

An important implication for the policy and practice agenda for nutrition-sensitive agriculture relates to the relative balance of crop and livestock focused initiatives in the region. Although there are important exceptions such as India's well-known and longstanding efforts in establishing a local model of dairy cooperatives, the balance of policy and practice attention in the region tends to pay less attention to the livestock sector than is often merited. Given that the review conducted here is clearest for livestock-nutrition linkages and further considering the global evidence accumulating around the importance of animal source foods in fighting undernutrition (Ruel et al., 2017), more South Asian policy attention to livestock sector strategies is called for. This would ideally also include programmes to promote improved sanitation around the management of livestock to prevent enteropathy-related nutrition impacts.

Methodologically, much of the literature continues to suffer from challenges relating to (lack of) causal identification of specific asset/input categories and nutrition linkages. Partly this arises from a preponderance in the literature of exploratory studies of agricultural 'drivers' of nutrition. Such studies tend not to isolate particular potential causal linkages of interest, but instead are interested in exploring any agriculture-nutrition linkages that may happen to exist. This focus may arise due to the fact that the agriculture-nutrition research agenda is still relatively new in many countries. Nevertheless, it is surprising that there are not more studies that identify specific hypotheses and draw on the suite of causal identification methods for observational data that have been the focus of so much attention in recent years. Training focus on specific hypotheses and making efforts to establish causality is a clear priority for this setting. Even where causal identification proves challenging due to data or other limitations, there is much scope for future literature in this area to undertake supplementary analyses (such as robustness tests and sensitivity analyses) that test the credibility of primary estimates of relationships (Athey and Imbens, 2017).

5. Competing interests

All authors state that they have no competing interests to declare.

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Appendix

See Table A1.

Table A1
Summary of studies included in the review.

Author, year, study location	Study design & Population	Ag. Input	Data analysis method	Data collection methods	Outcome	Key findings	Notes
Bageant et al. (2016), Nepal	Nepal Living Standards Survey (NLSS) – 1996, 2003 & 2011. 959 households from 1996–2003, anthropometric data from 2011 round of 2800 children (0–60 months)	Livestock ownership & milk consumption	Linear regression: Milk consumption & Anthropometric outcomes. Linear fixed effects model & Tobit model: livestock ownership & milk consumption	Milk consumption (& other dairy products): 'typical month' recall (separated own-produced and purchased). Livestock: aggregated data for milk-producing livestock	Anthropometric data: Children (0–60 months) HAZ & WAZ scores	(1) HH milk consumption positively associated with increasing HAZ scores (+100 g = +0.012SD, $p < 0.01$) but not WAZ scores (no significant association observed) (2) Livestock ownership associated with increased HH milk consumption eg. Each additional buffalo contributes 81–107 g milk/day for the HH (cow = 23–29 g). Anecdotal preference for buffalo milk	First 2 survey rounds were collected over the civil conflict – led to disappearances and deaths: significantly affected HH livestock ownership which led to a decline in milk consumption
Bhagowalia et al. (2012), India	Random sample from the India Human Development Survey (2004–2005). 15 HHs chosen from each primary sampling unit (village/urban block)	Livestock ownership	Ordinary least squares regression	IHDS data: Food consumption & Dietary Diversity (DD) score: 30-day recall	Household DD (HH DD) & children's HAZ & WHZ (0-5yrs)	(1) Agricultural HHs slightly higher rates of stunting & wasting. (2) DD score positively associated with having irrigation for at least 1 crop and owning buffalo. (3) Milk-producing livestock increased HH milk consumption (controlling for income) (4) Owning farming equipment significantly lowered DD scores. (5) No observed association with land ownership and DD scores (6) HH DD not associated with improved children's HAZ & WHZ scores.	Dietary recall to calculate HH DD scores aggregated both home-produced and purchased foods. Farm equipment is ownership of any type of equipment i.e. Tractor, thresher etc.
De Moura et al. (2016), Bangladesh	Dietary intake survey in 2 rural districts in the north (2007–2008). 237 women (14-50yrs) & 77 children (non-breastfed, 1-3yrs)	Biofortification: beta-carotene rice (Golden rice) – Vit. A	Used reported rice consumption, overall vit. A dietary intake & EAR of vit. A of different age groups. Simulated replacement of normal rice with Golden rice.	Dietary intake – 12 h weighed food records, 12 h food recall (2 surveys)	Vitamin A intake. Sensitivity analysis of different bioconversion ratios and % substitution	Baseline: 93% prevalence of inadequate vit. A intake in both sampled women and children. Various scenarios of beta-carotene concentration and % substitution showed reduced inadequate Vit. A intake by 42–78% and 35–71% in women and children respectively.	Simulations done in Indonesia & Philippines to – as expected higher impact would be observed in Bangladesh due to higher rice consumption. Limited representation as only done in 2 districts in N. Bangladesh (which are known to have a v. high rice consumption & poor nutritional status)
Dorsey et al. (2018), Nepal	PoSHAN Community Sample: 4853 children (6–59 months). Panel design.	Land ownership	Mixed effects logistic regression	HH interviews & anthropometric measurements	Stunting (HAZ ≤ -2)	HH crop production (None compared to > 5crops) & stunting = Adj. OR 1.36 (1.08–1.71, $p < 0.01$). Land area (None compared to > 0.5 ha) = Adj. OR 1.35 (1.08–1.75, $p < 0.01$). HH expenditure on ag. Inputs (None compared to any) = Adj. OR = 1.26 (1.05–1.51, $p < 0.05$).	HH crop production influence on odds of stunting only seen in Terai regions where agriculture production is more prominent compared to the hilly regions

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Table A1 (*continued*)

Author, year, study location	Study design & Population	Ag. Input	Data analysis method	Data collection methods	Outcome	Key findings	Notes
George et al. (2015), Bangladesh	Cross-sectional study: 216 randomly selected children (aged 6–30 months)	Livestock/animal ownership	Logistic regression	Questionnaire on environmental conditions. Stool samples and anthropometric measurements	HAZ, WHZ & WAZ	Animal pen in bedrooms: 14% of sample children & stunting OR: 2.43 (1.08–5.43, $p < 0.05$). Marginal non-significant increased OR for WHZ & WAZ (Z score -2).	
Harris-Fry et al. (2015), Bangladesh	Sample of 2809 women (15-49yrs) in 9 unions spread over Bangladesh (2011)	Land & Livestock ownership, Use of Vegetable garden	Linear Regression: Socio-demographic variables & Women's Dietary Diversity Score (WDDS)	24 hr recall: 9 food categories to measure WDDS (1 to 9 scale)	WDDS (9 groups: baseline average score 3.8)	After adjustment, only vegetable garden use was significantly associated with improved WDDS ($p = 0.003$). Less of an association seen with livestock & land ownership (livestock ownership linked to reduced levels of severe HH food insecurity).	Set up as an intervention – but this paper presents observational data from the control arm
Headey et al. (2017), Bangladesh	Baseline & Endline surveys of Alive & Thrive programme (2010–2014). 2214 Children (6-24mo).	Livestock ownership (faeces exposure)	Multivariate logit models – Ordinary least squares	Surveys: Observed faeces, reported ownership of livestock, measure anthropometry	Children's anthropometry (HAZ & WHZ)	HH presence of animal faeces associated with lower HAZ scores (-0.13, $p < 0.05$), but no significant relationship observed between HAZ or WHZ and livestock ownership.	Mean HAZ score in Bangladesh is -1.58 (steep increase of growth faltering between 6 and 20mo)
Jumrani and Birthal (2015), India	Cross sectional analysis of the Indian Household Demographic Survey (2004–2005).	Livestock ownership	Ordinary least squares regression & Probit model	Questionnaire and anthropometric measurements	Children's anthropometry (HAZ, WAZ & WHZ): Disaggregated 0–2 years & 2–5 years	No. of large ruminants (cow & buffalo): Underweight (2-5yrs) = -0.0096 ($p < 0.01$). Women Livestock care: Stunting (0-2yrs) = -0.0344 ($p < 0.1$), Underweight (0-2yrs) = -0.0365 ($p < 0.05$), Wasting (0–2yrs) = -0.0341 ($p < 0.1$). All other variables and anthropometric combinations were non-significant.	Authors explain that intra-household allocation may be a factor explaining weak relationship between livestock ownership & children's anthropometric measurements
Mulmi et al. (2017), Nepal	PoSHAN Community panel surveys (two rounds; 2013, 2014). 5978 children (6–59 months)	Land ownership	Logit regression models	HH interviews & 7-day food frequency questionnaire	Minimum Dietary Diversity (Min.DD ≥ 4 out of 7 food groups)	Land ownership (0 to 7 ha) &. Min. DD = 0.071, $p < 0.05$, (children aged 18–23 months). Much stronger associations seen in older, poorer children (lowest 1 & 2 quintile). Increased consumption of eggs, dairy and F&V. Marginal or no correlation in younger children.	
Paudel et al. (2012), Nepal	Community based case-control study (2010). Stunted vs. non-stunted children – 236 Children (6–59 months)	Pesticide exposure	Logistic regression model	Mothers were interviewed. Anthropometric measurements	Children's anthropometry (HAZ)	Stunted children were 3.5x more likely to be exposed to pesticides [OR = 3.51, CI = 1.33–9.23]	
Pritchard et al. (2017), India	Land ownership, agriculture, and household nutrition: a case study of north Indian villages	Land ownership	Mixed methods; groupwise (non-statistical) comparisons.	100 HHs surveyed at each site (2) (in 2011 & 2013). Further nutrition information in 2014 – in-depth qualitative interviews	kJ of different food groups for land & landless HHs	Landholding vs. Landless- Daily per capita kJ per HH – Site 1 (Kalyanagar) = F&V: 483 to 492 kJ, Milk: 1097 to 534 kJ, Total: 8909 to 8863 kJ. Site 2 (Bhimpur) = F&V: 534 to 497 kJ, Milk: 1494 to 769, Total: 10,072 to 8825	
Schmidt et al. (2016), India	Baseline survey (2010) of 1992 HHs before a WASH intervention.	Livestock ownership (faeces exposure) & Land ownership	Linear regression	Children < 2 yrs measured by the trained interviewers in 2013	HAZ of 824 children (< 2 years)	There was no significant difference between cow ownership (& no. of cows owned) and children's HAZ. No significant difference seen between land ownership (irrigated, non-irrigated or none owned) and HAZ scores.	

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Table A1 (*continued*)

Author, year, study location	Study design & Population	Ag. Input	Data analysis method	Data collection methods	Outcome	Key findings	Notes
Shively and Sunantsanuk (2015), Nepal	NLSS (Nepal Living Standards Survey) – 2010/2011: 5988 HHs	Land ownership	Multiple linear regression (HAZ), Binary Logistic regression (stunting)	HH questionnaire included 1769 children's anthropometry measurements	Child's HAZ (0–59 months) & Ratio of produced to total consumption	Farm size: non-significant association with HAZ (no figures given). HH's annual agricultural yield had a significant positive impact with HAZ & probability of stunting [1 t/ha yield increase = 0.07SD increase in HAZ & 2% decline in stunting probability] in children over 24 months	Greater degree of subsistence shows a negative impact on HAZ and increased probability of stunting. No analysis done on the type of production
Swaminathan and Thangavel (2015), India	3 farming villages: 260 participants (male & female, > 18yrs old)	Pesticide exposure: Category 1 – None/Minimal, Category 2 – Intermediate (Weeding or Harvesting), Category 3 – High (Mixing or Spraying)	Method of analysis not given	Diabetes: taking medication or Capillary glucose ≥200 mg/dl. Hypertension: taking medication or BP ≥140/90 mmHg	Diabetes & Hypertension (controlling for age, sex & BMI)	Diabetes prevalence: 24.6%. Diabetes: Category 3 vs. Category 1 = OR: 2.07 (95%CI: 1.01–4.24). Hypertension prevalence 35% – No significant relationship between categories observed. Lower avg. BMI in Category 3 compared to Cat. 1 (23.1 kg/m^2 vs. 23.9 kg/m^2)	Evidence of pesticide exposure and insulin resistance. Acknowledge several weaknesses and remaining confounders – paper presents a potential pathway. Skewed data – Category 3 had a higher baseline age and contained more men.

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