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A Nutrition-Sensitive Agroecology Intervention in Rural Tanzania Increases Children's Dietary Diversity and Household Food Security But Does Not Change Child Anthropometry: Results from a Cluster-Randomized Trial

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ABSTRACT

Background: There are urgent calls for the transformation of agriculture and food systems to address human and planetary health issues. Nutrition-sensitive agriculture and agroecology promise interconnected solutions to these challenges, but evidence of their impact has been limited.

Objectives: In a cluster-randomized trial (NCT02761876), we examined whether a nutrition-sensitive agroecology intervention in rural Tanzania could improve children's dietary diversity. Secondary outcomes were food insecurity and child anthropometry. We also posited that such an intervention would improve sustainable agricultural practices (e.g., agrobiodiversity, intercropping), women's empowerment (e.g., participation in decision making, time use), and women's well-being (e.g., dietary diversity, depression).

Methods: Food-insecure smallholder farmers with children aged <1 y from 20 villages in Singida, Tanzania, were invited to participate. Villages were paired and publicly randomized; control villages received the intervention after 2 y. One man and 1 woman "mentor farmer" were elected from each intervention village to lead their peers in agroecological learning on topics including legume intensification, nutrition, and women's empowerment. Impact was estimated using longitudinal difference-in-differences fixed-effects regression analyses.

Results: A total of 591 households (intervention: $n = 296$; control: $n = 295$) were enrolled; 90.0% were retained to study end. After 2 growing seasons, the intervention improved children's dietary diversity score by 0.57 food groups (out of 7; $P < 0.01$), and the percentage of children achieving minimum dietary diversity (≥ 4 food groups) increased by 9.9 percentage points during the postharvest season. The intervention significantly reduced household food insecurity but had no significant impact on child anthropometry. The intervention also improved a range of sustainable agriculture, women's empowerment, and women's well-being outcomes.

Conclusions: The magnitude of the intervention's impacts was similar to or larger than that of other nutrition-sensitive interventions that provided more substantial inputs but were not agroecologically focused. These data suggest the untapped potential for nutrition-sensitive agroecological approaches to achieve human health while promoting sustainable agricultural practices. *J Nutr* 2021;00:1–12.

Keywords: nutrition-sensitive agriculture, smallholder farmers, agrobiodiversity, food security, agroecology, sub-Saharan Africa, women's empowerment, participatory interventions, dietary diversity, child diet

Introduction

Food insecurity and malnutrition are two of the most pressing public health issues of our time. In 2019, 2 billion people experienced food insecurity, and 144 million children aged <5 y were stunted (1). Chronic undernutrition in the first 1000 d of life can impair health, cognitive function, and subsequent productivity, as well as increase the likelihood of poor mental health, illness, and mortality later in life (2, 3). Although agriculture has the potential to improve food insecurity and nutrition, it also contributes to biodiversity loss, land degradation, water and air pollution, and climate change (4). These can, in turn, undermine food production and health. Gender inequity, including unequal access to education, assets, decision making, household work, and exposure to violence, is also increasingly recognized as a significant driver of food insecurity and malnutrition globally (5).

The drivers of food insecurity and malnutrition, as well as their solutions, may be interconnected. For example, the 2030 Sustainable Development Goals (SDGs) house nutrition and agriculture targets under SDG 2 to “end hunger, achieve food security and improve nutrition, and promote sustainable agriculture” (6). Recent reports have recognized that improving biodiversity and ecosystem health is essential for a more sustainable food system (7, 8). Moreover, those working in agriculture and nutrition programs have recognized the importance of addressing gender inequity to improve agricultural productivity and nutritional status (9), and those working to improve gender equity have begun to emphasize the importance of addressing food insecurity and economic stressors in gender-specific programming and violence prevention (10).

Nutrition-sensitive agriculture (NSA) interventions—that is, agricultural interventions with the goal of improving human nutrition (9)—are an example of a solution that recognizes the interconnectedness of agriculture and nutrition. Unlike conventional agriculture interventions whose focus is on increased agricultural production and income, the primary objective of NSA interventions is to use food-based approaches to improve nutrition. Because improvements in women’s empowerment—that is, power and control over different dimensions of their lives (11)—are expected to increase the allocation of food and income from these interventions toward children’s nutrition (12), some NSA interventions also promote women’s empowerment as a way of achieving better nutrition (9, 13).

A recent systematic review of NSA interventions suggests that they can improve dietary practices (14). They have also been shown to have the potential to address other relevant causes of malnutrition, such as household food insecurity and lack of gender equity, although there are fewer trials measuring these outcomes. In contrast, the same systematic review found

little evidence of NSA impacts on children’s nutritional status. Moreover, NSA interventions have been criticized for their focus on the promotion of a biofortified crop, small-scale homestead vegetable production, or small farm animals, which leaves the primary food production system “in place,” ignoring emergent and salient issues of biodiversity, soil and water conservation, and energy use (15).

Agroecology is another approach to food production, but one that differs from most NSA in that care for the environment is central (16–18). Agroecology emphasizes ecological processes in agricultural practices, such as increasing agrobiodiversity; intercropping legumes with staple foods to fix nitrogen; improving soil quality through the incorporation of animal manure, compost, and plant residues (rather than synthetic fertilizers); and using natural predators, botanical sprays, and repellent plants instead of synthetic pesticides for pest management. These strategies have been demonstrated to increase farm productivity and yield stability while reducing the need for external agricultural inputs (18, 19).

Another feature that sets agroecology apart from NSA is the emphasis on addressing power inequities by using a participatory approach. Instead of being reliant on a set of “top-down,” one-size-fits-all technologies and practices, people are encouraged to integrate their knowledge, experiences, and lessons learned from experimentation to decide for themselves which practices to use and share (17, 20). Innovations among smallholder farmers are more likely to be carried out when they are both practical and harmonious with local and indigenous social and ecological contexts (16, 17, 20–22). By soliciting participation from the broader community, including marginalized populations such as indigenous groups, women, or food-insecure smallholder farmers, agroecological initiatives also seek to ameliorate social inequities (16, 22). The reduction of gender inequities in decision making and tasks is particularly emphasized in agroecology (23, 24).

Although there is considerable evidence of the impacts of agroecological practices on agricultural outcomes and the environment, there is a widely acknowledged need for a better understanding of their impacts on nutrition and social equity outcomes (15, 17–19). Recent studies have shown some evidence of improved child growth, food insecurity, wealth, and dietary diversity, but research design issues, such as lack of a control group, preclude definite conclusions (25–27).

Therefore, we designed an agriculture intervention that sought to improve child nutrition (i.e., is nutrition-sensitive) and that emphasized agroecological practices (i.e., participatory sustainable agriculture and social equity). We evaluated the impacts of this nutrition-sensitive agroecological intervention using a cluster-randomized effectiveness trial among rural Tanzanian smallholder farmers. The trial was clustered at the village level because the intervention relied on farmers within the same village advising and learning from each other. The primary outcome was improvements in children’s dietary diversity scores (DDSs) and minimum dietary diversity (MDD) (28) (Supplemental Figure 1, Supplemental Table 1). Secondary outcomes were household food insecurity (29) and child anthropometry [i.e., height-for-age *z* score (HAZ), stunting, weight-for-height *z* score (WHZ), and wasting] (30). We additionally measured 3 other groups of indicators that could shape the primary and secondary outcomes—sustainable agriculture practices, women’s empowerment, and women’s well-being (Supplemental Figure 1, Supplemental Table 1)—recognizing that there are numerous pathways by which the primary and secondary outcomes may be shaped (9).

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Supplemental Figures 1–11, Supplemental Tables 1–9, and Supplemental Text 1 and 2 are available from the “Supplementary data” link in the online posting of the article and from the same link in the online table of contents at <https://academic.oup.com/jn/>.

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Abbreviations used: A-WEAI, Abbreviated Women’s Empowerment in Agriculture Index; DDS, dietary diversity score; HAZ, height-for-age *z* score; HFIAS, Household Food Insecurity Access Scale; MDD, minimum dietary diversity; MDD-W, Minimum Dietary Diversity for Women; NSA, nutrition-sensitive agriculture; pp, percentage points; SDG, Sustainable Development Goal; SNAP-Tz, Singida Nutrition and Agroecology Project; WHZ, weight-for-height *z* score.

Methods

The Singida Nutrition and Agroecology Project (SNAP-Tz; clinicaltrials.gov identifier: NCT02761876) was a collaboration between the nongovernmental organization (NGO) ActionAid Tanzania, local government (i.e., the Singida Rural District Council), and Tanzanian and US-based university researchers. Additional details on study implementation are found in **Supplemental Figure 2** and **Supplemental Text 1, Study timeline**.

Setting

Singida Rural District, in Tanzania's semiarid central region, has one of the highest poverty rates in Tanzania (31). Agricultural and livestock activities are the primary livelihoods, with households cultivating an average of 2.15 acres (32). Agricultural activities follow a unimodal pattern (33); planting is in November and December, and harvesting occurs in May–July.

Food insecurity is prevalent in the region: in 2016, 49% of households had low household dietary diversity (<3 out of 12 food groups) (34). Children's nutritional intake is inadequate. Only 6.9% and 4.2% of children aged 6–23 mo in 2014 met MDD (i.e., ≥ 4 food groups in the prior 24 h) and had a minimum acceptable diet (i.e., meeting both MDD and minimum meal frequency), respectively; one-third of children aged <5 y were stunted (35). Gender inequities are pervasive—for example, women spent more than twice the amount of time on household tasks and had less access to productive resources compared with men (10).

Study participants

Village selection started with the identification of 33 villages by the Singida Rural District Council. Then, in collaboration with Singida Rural District officers, 22 were identified as candidate sites in October 2015 based on their village leadership's willingness to participate in the study, having >200 children aged <5 y, and not participating in other interventions (**Supplemental Figure 3**). Twenty villages were ultimately included, from which 10 pairs were formed based on the number of months of food security, predominant soil type, and proximity to health clinics (see “October 2015” in Supplemental Text 1).

To identify eligible and interested households, study staff described the study in each of the 20 villages at meetings open to all community members in December 2015. Household eligibility criteria included 1) being food insecure as defined by the community, 2) having a child aged <1 y in January 2016, 3) having access to land and planning to farm in the coming year, 4) intending to reside in that village for the next 3 y, and 5) being interested in experimenting with new farming techniques. Village leaders then invited ~30 eligible households that met these criteria to participate, and their eligibility was confirmed during the first survey in January and February 2016. Ultimately, 591 households agreed to participate (**Supplemental Figure 3**). In each of the 20 villages, 2 “mentor farmers” were elected by fellow study participants in February 2016 (see “End of February 2016” in Supplemental Text 1).

Random allocation of villages to the intervention or control arms was done publicly by mentor farmers drawing slips from a hat in March 2016. The staff who conducted data collection, data entry, and data cleaning were unaware of the villages' intervention status. However, due to the participatory nature of the intervention and the presence of the lead author in the intervention villages during implementation, full blinding was not possible.

SNAP-Tz was powered to detect a simple difference of means of 0.3 food groups in children's DDSs [out of 7 (28)] at endline using an α of 0.05 and power of 0.90. An SD of 1.21 and the intraclass correlation of 0.02 used in the calculation were based on our pilot survey in the area (36, 37).

Intervention

Initial activities.

One woman and 1 man mentor farmer from each of the 10 intervention villages ($n = 20$) learned about sustainable agriculture practices, nutrition, women's empowerment, and participatory learning through

2 sets of activities. In April 2016, they participated in a week-long learning exchange with the farmers of the Malawi Farmer-to-Farmer Agroecology study (26). In July 2016, they participated in a 2-week-long training led by Action Aid Tanzania using the Farming for Change curriculum (38). The curriculum is integrative, linking agroecology with climate change, human nutrition, gender, and social equity; it is also participatory, focusing on experiential-based learning and theater.

Village-level activities.

Beginning in August 2016, mentor farmers were encouraged to invite both men and women from intervention households to monthly meetings and to visit each household quarterly, at minimum. They were encouraged to share with intervention households lessons learned from their training in any way they thought would be effective and promote experimentation with and exchange ideas and challenges about these new agroecological techniques among intervention households. There was not a standardized set of messages for mentor farmers to discuss because the intervention used a participatory agroecological learning approach with context-specific problem-solving. To facilitate this, SNAP-Tz provided mentor farmers with a bicycle and a small stipend (~\$43 monthly).

Project-level activities.

In December 2016 and 2017, intervention households received 0.5–3 kg of legume seeds (enough for 0.25 acres) to encourage agroecological experimentation. They could select 2 types of seeds from among 6 options: groundnuts (*Arachis hypogaea*), cowpea (*Vigna unguiculata*), soybean (*Glycine max*), pigeon pea (*Cajanus cajan*), common beans (*Phaseolus vulgaris*), and lablab (*Lablab purpureus*).

Every quarter, mentor farmers and representatives of all partner organizations met to reflect on progress to date and decide on upcoming intervention activities, beginning in November 2016. These activities were decided based on mentor farmers' reports on successes and challenges, study staff observations during village visits, and the latest survey results.

Control villages.

The control villages did not receive any interventions until after 2 growing seasons. In December 2018, as SNAP-Tz was concluding, mentor farmers in control villages were trained by intervention village mentor farmers using the Farming for Change curriculum. They also received $\frac{1}{4}$ acre's worth of legume seeds selected from among the 6 options offered to the intervention villages.

Data collection and operationalization

Comprehensive surveys were conducted every growing season (January and February) from 2016 to 2019; shorter surveys were conducted every postharvest season (July and August). Surveys tracked the index children (aged <1 y in January 2016) and their parents across time. For most outcomes, data collected in 2016 were treated as baseline, and data collected in 2017–2019 were evaluated for evidence of intervention impacts. To assess the impact on children's diet, household food insecurity, child anthropometry, and women's diet, data on these outcomes collected in January 2017 were also used as baseline values in the regression models. At that point, the intervention had begun, but no crops were yet harvested. (See Supplemental Figure 2 and Supplemental Text 1 for more details on the timing of baseline data collection.)

The registered primary outcome (NCT02761876) was the index child's diet, measured by DDS (when the child was aged ≥ 6 mo), and whether a child met the MDD (28) (**Supplemental Figure 1**). MDD is considered to be met when children aged 6–23 mo consume ≥ 4 (out of 7) food groups. We used the 2011 WHO guidelines for this [rather than ones ratified in December 2017 (39)] because the 4-group threshold was the primary registered outcome. We also calculated the MDD for children aged >23 mo because there is no well-established indicator for dietary diversity in older children. Dietary data were collected by interviewing mothers using an FFQ adapted to the local diet. (More details on all measurements are provided in Supplemental Table 1.)

We also collected data on the following secondary outcomes: household food insecurity and child anthropometry. Household food insecurity was measured by jointly interviewing men and women using the Household Food Insecurity Access Scale (HFIAS). We used these data to construct 2 indicators: a continuous score, where higher scores indicate greater food insecurity, and a binary outcome that equaled 1 if a household experienced moderate or severe food insecurity and 0 otherwise (29). Child anthropometric measurements were made by a trained team of local nurses and nutritionists using best practices (40). Using these data as well as information on child age, we calculated HAZs and WHZs and determined their stunting and wasting status (30).

We collected data on plausible mechanisms by which these changes could occur: sustainable agriculture practices, gender equity, and women's well-being (Supplemental Figure 1). These indicators were not included in our trial registration. Indicators of sustainable agriculture practices included crop species richness, an indicator of agrobiodiversity (41); whether households intercropped legumes and staple foods in any of their agricultural fields; the number of sustainable practices households used to improve soil health (42); and the number of sustainable pest management strategies used (42). These data were collected by jointly interviewing men and women. Because seeds were distributed to the control group in December 2018, we did not measure sustainable agricultural practices in January 2019 (see Supplemental Text 1).

We chose 5 indicators of women's empowerment that would either allow for comparisons to previous studies or were germane to changes in food insecurity and children's diet (Supplemental Figure 1). We asked women about their participation in decision making in agriculture practices and income allocation using decision-making items included in the Abbreviated Women's Empowerment in Agriculture Index (A-WEAI) (43). Answers were scored 0 if the woman had no say, 0.5 if jointly decided, and 1 if the woman had the final say; we present mean scores. We did not use the A-WEAI cutoff for empowerment because most women reported participating in joint decision making in ≥ 1 activity, which would have them classified as adequately empowered; further probing during the pilot phase revealed that men generally made the decision, and women acquiesced (44). Women's time use in the previous 24 h was tracked using the A-WEAI methodology. We measured the types of help women received from their husbands by asking whether partners had participated in each of 6 tasks that men rarely do, as identified in an iterative pile-sort activity during the pilot study (44). Finally, we measured overall empowerment with the 5 domains of empowerment score of the A-WEAI (43).

To assess women's well-being, we used indicators that have been validated either globally or among similar populations. These were Minimum Dietary Diversity for Women (MDD-W) (45), adequacy of social support using the Perceived Social Support Scale (46), and risk of probable depression using the Center for Epidemiologic Studies–Depression Scale (47). To measure probable depression, we used a cutoff value that has been validated for use among similar populations in East Africa (48) (Supplemental Table 1).

Data analysis

We estimated the following difference-in-differences models:

$$Y_{it} = \alpha + \beta_1 D_i * T_{it} + \beta_2 D_i + \beta_3 Y'_t + Z_i + \beta_4 X'_{it} + \varepsilon_{it} \quad (1)$$

$$Y_{it} = \alpha + \beta'_1 D_i * T'_{it} + \beta_2 D_i + \beta'_3 Y'_t + Z_i + \beta_4 X'_{it} + \varepsilon_{it} \quad (2)$$

where Y_{it} is the outcome of interest for household i at time period t ; D_i is a dummy variable that equals 1 if the household was in an intervention village; T_{it} is a dummy variable that equals 1 for all survey rounds that occurred after the intervention began (i.e., July 2017 onwards; see Supplemental Figure 2); and T'_{it} is a vector of dummy variables, each equaling 1 for each survey round that occurred after the intervention began. Thus, the coefficient estimates for the interaction term (β_1) in Equation 1 capture the average effect of SNAP-Tz over the entire period after the intervention began. By contrast, the vector of coefficient estimates for the interaction term (β'_1) in Equation 2 captures survey

estimates of the impact of SNAP-Tz specific to that round. We included a vector of survey-round dummy variables (Y'_t) that allowed us to control for effects common to all households specific to that survey round. We controlled for time-invariant household fixed effects through the inclusion of Z_i . X'_{it} captures time-varying characteristics such as child's age for child outcomes; ε_{it} is the white noise error term.

We estimated Equations 1 and 2 using least squares regressions for continuous outcomes as well as dichotomous outcomes; the latter are estimated as linear probability models. For all models, SEs were estimated using the wild cluster bootstrap-t procedure, which, compared with conventional methods of calculating cluster-robust SE, provides a less biased estimate of SEs when the number of clusters in the sample is < 30 (49, 50).

Robustness analyses included estimating intervention effects using multilevel regression models accounting for the hierarchical nature of the data (51); these results are presented in Supplemental Tables 2–7. To further assess the intervention impacts, we also estimated Equation 1 for food groups comprising child's dietary diversity, individual crops grown, particular sustainable agriculture practices to improve soil health and manage pests, types of women's time use activities, domains of A-WEAI, and food groups comprising women's dietary diversity (Supplemental Figures 4–10). For domains relating to mechanisms for which we have > 2 indicator outcomes (sustainable agriculture, women's empowerment, and women's well-being), we also calculated Romano–Wolf P values (52) to explore the impact of multiple testing; these P values were only minimally different from the original P values (Supplemental Tables 5–7). All analyses were done using Stata version 14 (StataCorp).

Ethical approval and consent

Written consent to participate in the study was obtained from every household before the baseline survey. A repeated statement of consent was collected every subsequent year before any data collection. The study received approval from Cornell University's Institutional Review Board (1,511,005,983), Tanzania's Commission for Science and Technology (2018–207-NA-2015–121), and Tanzania's National Institute for Medical Research.

Results

Baseline results

At the baseline survey in January 2016, 591 households agreed to participate in the study (Table 1, Supplemental Figure 3). The majority were married monogamously, of the Nyaturu ethnic group, and reported farming as their main occupation. Households had ~ 6 or 7 members. On average, children's mothers were aged 29.7 y and had ~ 5.9 y of formal education.

Attrition

All 20 villages remained in the project until the endline. The rate of household loss to follow-up varied over time (Supplemental Figure 3). At endline, loss to follow-up was 10.0%. Households in the intervention villages were more likely to attrit (13.6%) compared with those in control villages (6.4%). Analysis of baseline characteristics revealed that women from households that attrited were younger, and households that attrited were engaged in ~ 0.1 more sustainable soil health practices (Supplemental Table 8).

Intervention delivery

Most participants living in intervention villages reported receiving seeds (90.4% in 2017, 98.3% in 2018) and knew the correct names of their mentor farmers (86.1% of women, 71.4% of men) by endline. Participation in SNAP-Tz activities varied over time (Supplemental Figure 11). At endline, 58% and 55% of adult women and men participants who lived in an

TABLE 1 Baseline characteristics of participants in the Singida Nutrition and Agroecology Project, by intervention arm¹

	Control (n = 296)	Intervention (n = 295)
Household characteristics		
Household size	6.4 ± 2.2	6.3 ± 2.3
Marital status		
Married, monogamous	85.1	84.1
Married, polygamous	8.5	7.5
Separated/divorced/widowed	6.4	8.5
Asset index score ²	9.2 ± 2.9	8.6 ± 2.8
Maternal characteristics		
Age, y	29.9 ± 7.4	29.6 ± 7.8
Education, y	5.9 ± 2.6	6.0 ± 2.8
Muslim	68.9	76.9
Nyaturu ethnic group	96.9	95.9
Children's characteristics		
Female	52.2	51.5
Age, mo	5.9 ± 3.2	5.8 ± 3.4
Primary outcome: children's dietary diversity		
Children's dietary diversity score (0–7 food groups), postharvest season	2.3 ± 1.1	2.2 ± 1.4
Children's dietary diversity score (0–7 food groups), growing season	1.8 ± 0.9	1.8 ± 1.0
Child met minimum dietary diversity, postharvest season	13.5	15.5
Child met minimum dietary diversity, growing season	3.4	5.1
Secondary outcome: food security		
Household Food Insecurity Access Scale (0–27) at postharvest season	6.4 ± 5.6	7.2 ± 5.9
Household Food Insecurity Access Scale (0–27) at growing season	12.3 ± 6.4	12.5 ± 6.5
Experience moderate or severe food insecurity at postharvest season	69.9	72.8
Experience moderate or severe food insecurity at growing season	88.2	85.4
Secondary outcome: child anthropometry		
Child's height-for-age z score	−1.4 ± 1.1	−1.4 ± 1.1
Child's weight-for-height z score, postharvest season	−0.69 ± 1.08	−0.54 ± 1.00
Child's weight-for-height z score, growing season	−0.51 ± 1.05	−0.42 ± 0.95
Child was stunted	26.1	27.8
Child was wasted, postharvest season	12.2	8.5
Child was wasted, growing season	7.1	5.1
Sustainable agriculture practices		
Crop species richness	1.7 ± 0.9	1.8 ± 0.9
Households intercropped staple foods with legumes	4.8	6.7
Number of sustainable agriculture practices to improve soil health (0–9)	0.33 ± 0.52	0.46 ± 0.54
Number of sustainable agriculture practices to manage pests (0–7)	0.30 ± 0.54	0.33 ± 0.51
Women's empowerment		
Women's agricultural decision-making power (0–1)	0.37 ± 0.25	0.37 ± 0.26
Women's income allocation decision-making power (0–1)	0.38 ± 0.21	0.35 ± 0.22
Women's time expenditure on agriculture or paid work, h	3.5 ± 2.2	3.7 ± 2.0
Women's time expenditure on household work or child care, h	10.4 ± 3.2	10.2 ± 3.2
Women's time expenditure on leisure, h	1.9 ± 1.9	1.8 ± 1.7
Number of activities in which husband helps (0–6)	2.1 ± 1.7	2.1 ± 1.8
Abbreviated Women's Empowerment in Agriculture Index (0–1)	0.45 ± 0.16	0.46 ± 0.18
Women's well-being		
Met minimum dietary diversity (≥5 out of 10 food groups)	13.5	15.9
Adequate social support (≥3 out of 4)	81.4	75.5
Probable depression (≥17 out of 60)	40.5	41.8

¹Values are means ± SDs or percentages.

²Asset index score (range: 3.0–18.7) was developed using principal component analysis from household's ownership of any land, metal roof, electricity, ox plow, solar panels, cell phone, radio, modern beds, mosquito net, books, bicycle, and cattle.

intervention village, respectively, reported attending ≥1 village-level SNAP-Tz meeting in the prior month.

Primary outcome: children's dietary diversity

At baseline, children aged >6 mo consumed 2.3 ± 1.3 and 1.8 ± 0.9 food groups during the postharvest and growing seasons, respectively. During the postharvest season,

the intervention increased children's DDS by 0.57 food groups (Figure 1A; full regression results are shown in Supplemental Table 2, column 1). Analyses by food group revealed an increased proportion of children consuming eggs [5.8 percentage points (pp), $P = 0.03$], dairy (8.8 pp, $P = 0.04$), meat (16.3 pp, $P < 0.01$), and legumes (12.9 pp, $P < 0.01$) (Supplemental Figure 4). Children's dietary diversity in the

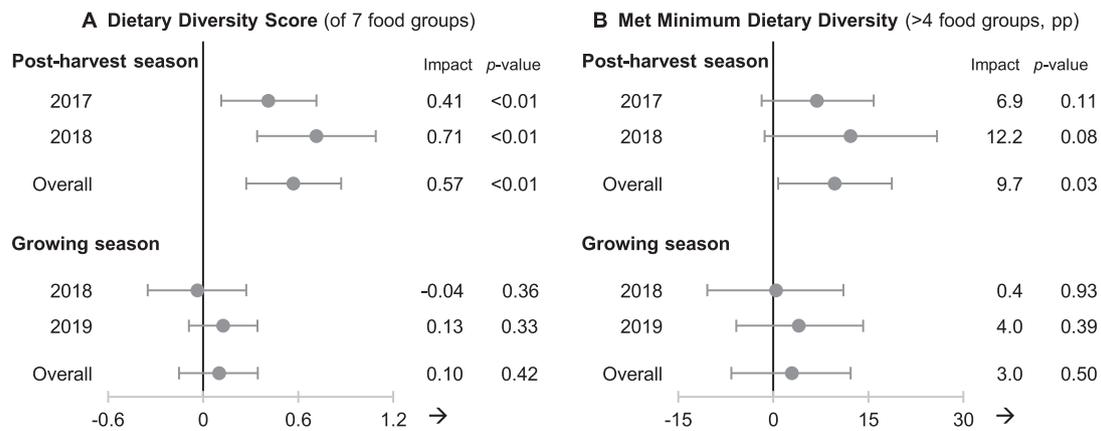


FIGURE 1 Intention-to-treat impact of the Singida Nutrition and Agroecology Project intervention on children's diet, the primary study outcome ($n = 591$). (A) β coefficients and 95% CIs of the intervention impact on children's dietary diversity score (range: 0–7 food groups). At baseline, children ate (mean \pm SD) 2.3 ± 1.1 and 1.8 ± 0.9 food groups during the postharvest and growing seasons, respectively. (B) β coefficients and 95% CIs of the impact on the proportion of children meeting minimum dietary diversity. At baseline, 14.5% and 4.2% of the children met the minimum acceptable diet during the postharvest and growing seasons, respectively. β coefficients were derived using linear regression for continuous outcomes and linear probability regression for binary outcomes, controlling for child age and household-level fixed effects; 95% CIs were calculated accounting for clustering at the village level using the wild bootstrap method. Full regression results are presented in Supplemental Table 2. The arrows indicate the direction of favorable outcome. pp, percentage points.

growing season did not change significantly (0.10 food groups, $P = 0.42$) (Figure 1A).

At baseline, 14.5% and 4.2% of children aged >6 mo met MDD during the postharvest and growing seasons, respectively. The intervention increased the proportion of children meeting the MDD by 9.7 pp in the postharvest season at endline ($P = 0.03$) but not in the growing season (3.0 pp, $P = 0.50$) (Figure 1B; Supplemental Table 2, columns 9 and 13).

Secondary outcomes

Food insecurity.

At baseline, the mean HFIAS was 6.8 ± 5.7 and 12.4 ± 6.4 in the postharvest and growing seasons, respectively. The intervention reduced HFIAS by 2.48 ($P < 0.01$) and 1.91 ($P < 0.01$) points in the postharvest and growing seasons, respectively (Figure 2A;

Supplemental Table 3, columns 1 and 5). At baseline, 71.4% and 86.8% of households experienced moderate or severe food insecurity, respectively. The intervention reduced this by 12.5 pp ($P < 0.01$) and 9.0 pp ($P = 0.03$) in the postharvest and growing seasons, respectively (Figure 2B) (Supplemental Table 3, columns 9 and 13).

Child anthropometry.

At baseline, the mean child HAZ was -1.4 ± 1.1 , and 26.9% of children were stunted. Mean child WHZ during the postharvest season was -0.62 ± 1.04 , and 10.4% of children were wasted. Mean child WHZ during the growing season was -0.46 ± 1.01 , and 6.1% of children were wasted. The intervention did not have a statistically significant impact on any measure of child anthropometry (Figure 3, Supplemental Tables 4A and 4B).

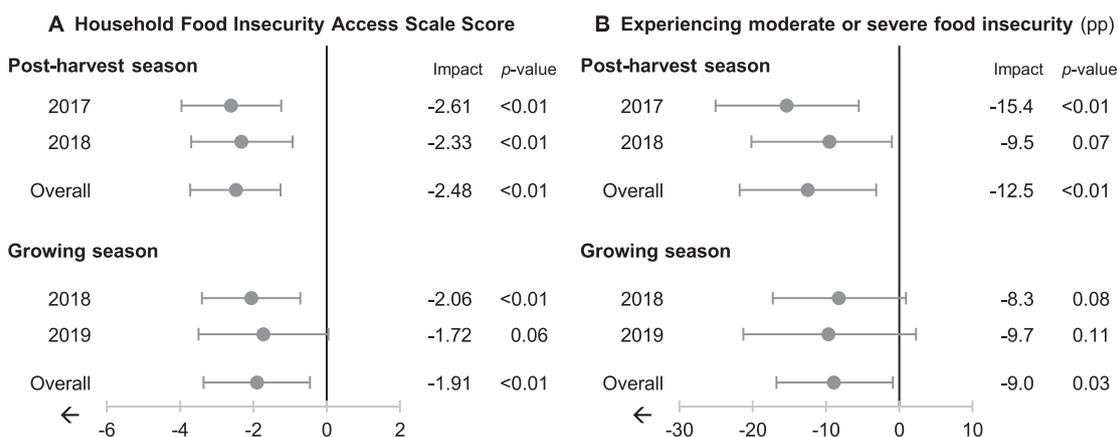


FIGURE 2 Intention-to-treat impact of the Singida Nutrition and Agroecology Project intervention on food security, a secondary study outcome ($n = 591$). (A) β coefficients and 95% CIs of the intervention impact on the Household Food Insecurity Access Scale score. At baseline, the Household Food Insecurity Access Scale score (mean \pm SD) was 6.8 ± 5.7 and 12.4 ± 6.4 at the postharvest and growing seasons, respectively. (B) β coefficients and 95% CIs of the impact on the proportion of households experiencing moderate or severe food insecurity. At baseline, 71.4% and 86.8% of households experienced moderate or severe food insecurity during the postharvest and growing seasons, respectively. β coefficients were derived using linear regression for continuous outcomes and linear probability regression for binary outcomes, controlling for household-level fixed effects; 95% CIs were calculated accounting for clustering at the village level using the wild bootstrap method. Full regression results are presented in Supplemental Table 3. The arrows indicate the direction of favorable outcome. pp, percentage points.

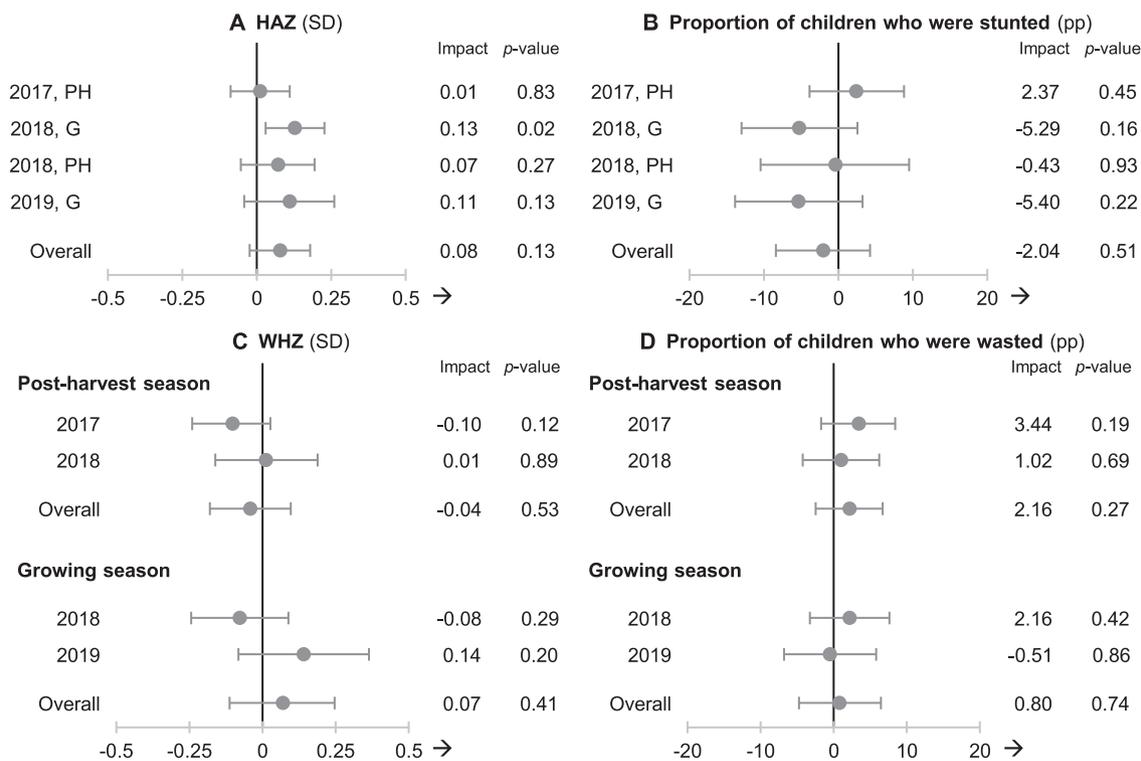


FIGURE 3 Intention-to-treat impact of the Singida Nutrition and Agroecology Project intervention on child anthropometry, a secondary study outcome. (A and C) β coefficients and 95% CIs of the intervention impact on HAZ and WHZ, respectively. At baseline, children's HAZ (mean \pm SD) was -1.4 ± 1.1 , children's WHZ at postharvest seasons was -0.62 ± 1.04 , and children's WHZ at growing seasons was -0.46 ± 1.01 . (B and D) β coefficients and 95% CIs of the impact on the proportion of children who were stunted (B) and wasted (D). At baseline, 26.9% of children were stunted, 10.4% were wasted during the postharvest seasons, and 6.1% were wasted during the growing seasons. β coefficients were derived using linear regression for continuous outcomes and linear probability regression for binary outcomes, controlling for child age and household-level fixed effects; 95% CIs were calculated accounting for clustering at the village level using the wild bootstrap method. Full regression results are presented in Supplemental Tables 4a and 4b. The arrows indicate the direction of favorable outcome. HAZ, height-for-age z score; pp, percentage points; WHZ, weight-for-height z score.

Sustainable agriculture practices

At baseline, each household grew 1.8 ± 0.9 species of crops; the intervention increased crop species richness by 1.05 species ($P < 0.01$) (Figure 4A; Supplemental Table 5, column 1). The increase in crop species richness resulted from the intervention increasing the likelihood that households grew legumes (Supplemental Figure 5). At baseline, 5.7% of households intercropped legumes with staple foods. The intervention increased intercropping by 42.6 pp ($P < 0.01$) (Figure 4B; Supplemental Table 5, column 5).

At baseline, the average household used 0.39 ± 0.53 sustainable practices to improve soil conservation and health (out of 9) (Figure 4C; Supplemental Table 5, column 9). The intervention increased this by 0.36 practices ($P < 0.01$), which included increases in planting in pits (8.3 pp, $P = 0.05$), building ridges (8.2 pp, $P = 0.01$), and soil mixing (11.6 pp, $P < 0.01$) (Supplemental Figure 6).

At baseline, each household used 0.32 ± 0.53 of 7 sustainable practices to manage pests. The intervention increased this by 0.52 practices ($P = 0.02$) (Figure 4D; Supplemental Table 5, column 13), including increases in the proportion of households using botanical pesticides (10.7 pp, $P < 0.01$) and ash (14.5 pp, $P < 0.01$) (Supplemental Figure 7).

Women's empowerment

At baseline, women's mean income allocation and agricultural decision-making power on a 0–1 scale were 0.37 ± 0.25 and

0.36 ± 0.22 , respectively. The intervention increased women's decision-making power in income allocation (0.07 on a unitless scale from 0 to 1, $P < 0.01$) (Figure 5A; Supplemental Table 6, column 5) but not agricultural decisions (Figure 5B; Supplemental Table 6, column 1).

At baseline, women reported that their husbands had helped with 2.1 ± 1.8 household chores in the past month; the intervention increased this by 0.36 tasks ($P = 0.05$) (Figure 5C; Supplemental Table 6, column 13). The intervention did not increase women's time spent on household work and child care (Figure 5D; Supplemental Figure 8; Supplemental Table 6, column 9).

At baseline, the mean empowerment score according to A-WEAI was 0.46 ± 0.17 . The intervention increased this score by 0.15 points ($P < 0.01$) (Figure 5E; Supplemental Figure 10; Supplemental Table 6, column 17).

Women's well-being

During the baseline growing season, 14.7% of women met the MDD-W; the intervention increased this by 15.2 pp ($P < 0.01$) (Figure 6A; Supplemental Table 7, column 1). This was driven by increased consumption of vitamin A-rich fruits and vegetables (8.9 pp, $P = 0.03$), other vegetables (9.2 pp, $P = 0.02$), and other fruits (13.7 pp, $P < 0.01$) (Supplemental Figure 10).

At baseline, 78.4% of women reported adequate social support; the intervention increased this proportion by

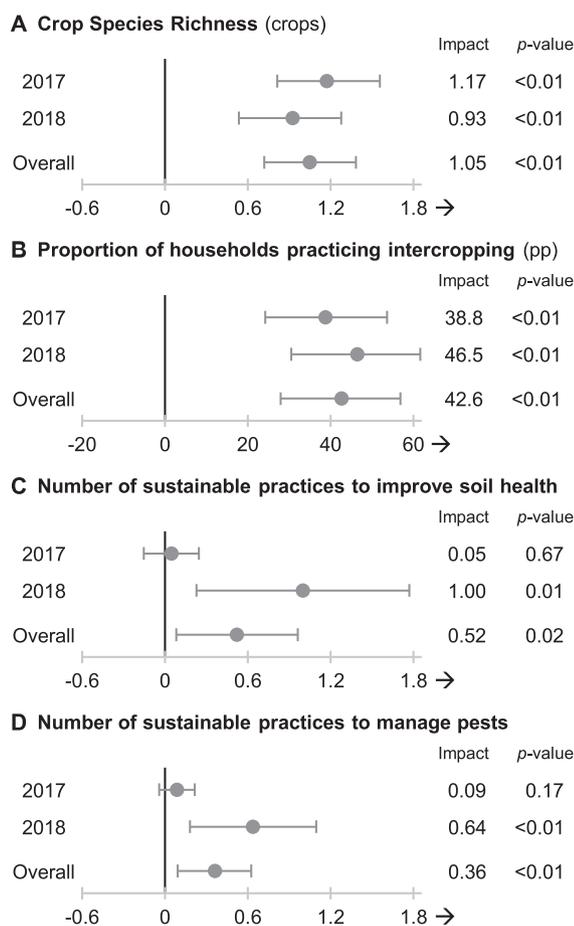


FIGURE 4 Intention-to-treat impact estimates of the Singida Nutrition and Agroecology Project intervention on sustainable agriculture practices ($n = 591$). At baseline, the crop species richness (mean \pm SD) was 1.8 ± 0.9 crops, 5.7% of households practiced intercropping, the number of sustainable practices to improve soil health was 0.39 ± 0.53 , and the number of sustainable practices to improve pest management was 0.32 ± 0.53 . β coefficients were derived using linear regression for continuous outcomes and linear probability regression for binary outcomes, controlling for household-level fixed effects; 95% CIs were calculated accounting for clustering at the village level using the wild bootstrap method. Full regression results are presented in Supplemental Table 5. The arrows indicate the direction of favorable outcome. pp, percentage points.

13.3 pp ($P = 0.01$) (Figure 6B; Supplemental Table 7, column 5). At baseline, 41.2% of women were experiencing probable depression; the intervention reduced this by 11.6 pp ($P = 0.04$) (Figure 6C; Supplemental Table 7, column 9).

Discussion

SNAP-Tz increased DDSs, our primary outcome, by 0.57 ($P < 0.01$) food groups in index children. SNAP-Tz raised the percentage of index children who met MDD by 9.7 pp. To our knowledge, this is the first study to demonstrate that an NSA intervention that included a considerable emphasis on agroecological practices could improve DDSs for young children. The magnitude of the impact is noteworthy. Impacts on dietary diversity in other NSA interventions ranged from 0.11 to 0.68 food groups (53–56). Results from SNAP-Tz are

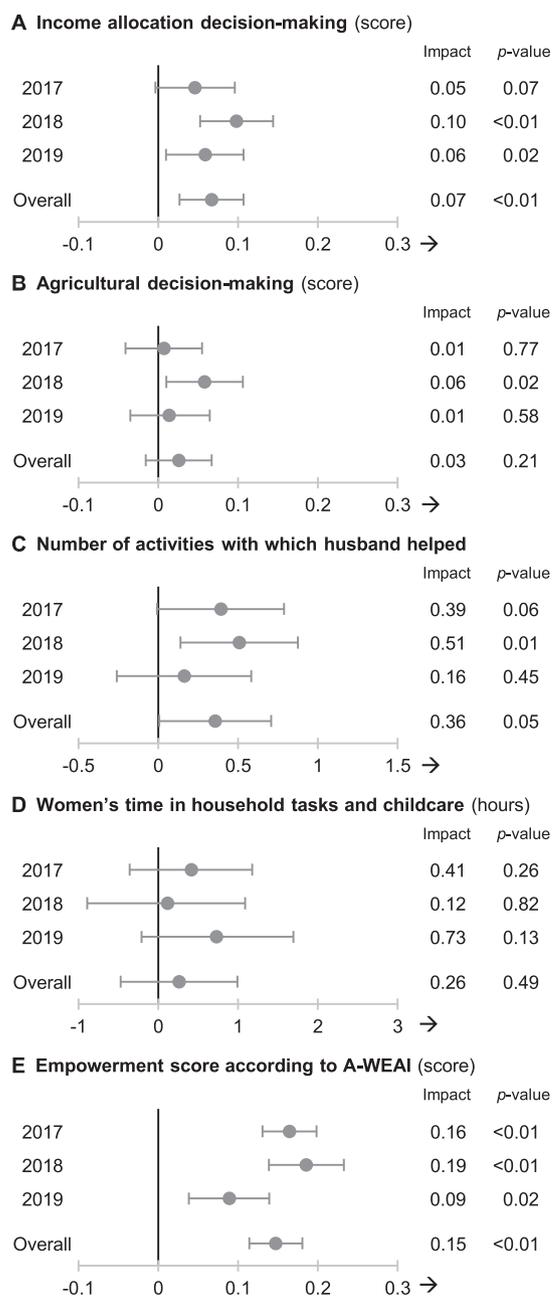


FIGURE 5 Intention-to-treat impact estimates of the Singida Nutrition and Agroecology Project intervention on women's empowerment ($n = 591$). At baseline, women's income allocation and agriculture decision-making power (mean \pm SD) was 0.37 ± 0.26 and 0.36 ± 0.22 , respectively; husbands helped with 2.1 ± 1.8 household chores in the past month; women spent 10.3 ± 3.2 h on household work in the previous 24 h; and the empowerment score according to A-WEAI was 0.46 ± 0.17 . β coefficients were derived using linear regression for continuous outcomes and linear probability regression for binary outcomes, controlling for household-level fixed effects; 95% CIs were calculated accounting for clustering at the village level using the wild bootstrap method. Full regression results are presented in Supplemental Table 6. The arrows indicate the direction of favorable outcome. A-WEAI, Abbreviated Women's Empowerment in Agriculture Index.

at the upper end of this range and were achieved using fewer external inputs compared with other NSA interventions. As an illustration, an NSA study in Rwanda provided dairy cows and goats (57), whereas another NSA study in Zambia provided

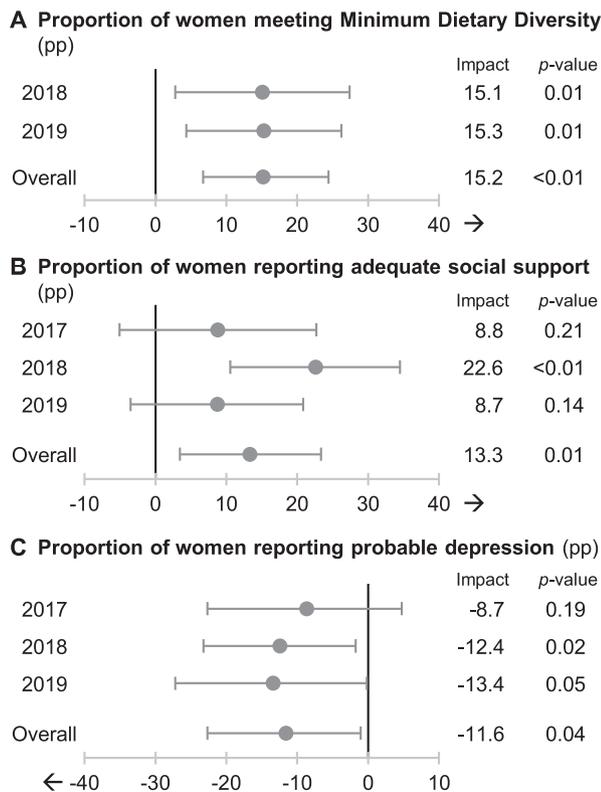


FIGURE 6 Intention-to-treat impact estimates of the Singida Nutrition and Agroecology Project intervention on women's well-being ($n = 591$). At baseline, 14.7% women achieved minimum dietary diversity, 78.4% reported adequate social support, and 41.2% reported probable depression. β coefficients were derived using linear regression for continuous outcomes and linear probability regression for binary outcomes, controlling for household-level fixed effects; 95% CIs were calculated accounting for clustering at the village level using the wild bootstrap method. Full regression results are presented in Supplemental Table 7. The arrows indicate the direction of favorable outcome. pp, percentage points.

seeds twice a year for 4 y, as well as goats, chickens, and agricultural tools (53).

We observed a significant impact on 1 of our 2 secondary outcomes. SNAP-Tz reduced HFIAS scores by 1.91 and 2.48 points in the growing and postharvest seasons, respectively (Figure 2). SNAP-Tz also reduced the prevalence of severe or moderate food insecurity by 9.0 pp in the growing season and 12.5 pp in the postharvest season. This is larger than the sole NSA impact evaluation that reported an impact on household food insecurity using the HFIAS. In that study, HFIAS was reduced by 0.4 points (58). The 2 agroecological studies that used the HFIAS reported impacts similar to SNAP-Tz; they reduced HFIAS by 3.21 and 2.06 points (26, 59). As has been the case for the majority of NSA interventions (14), we found no impact on any child anthropometric measurements (Figure 3).

We measured outcomes along 3 pathways through which SNAP-Tz may have improved children's dietary diversity and reduced household food insecurity: sustainable agriculture practices, women's empowerment, and women's well-being.

The intervention increased each household's agrobiodiversity by ~ 1 species (Figure 4). Given that the intervention provided seeds, this increase in agrobiodiversity, although encouraging, is intuitive and similar to other NSA and agroecology

interventions (58). Although the impact of agrobiodiversity on mothers' and children's dietary diversity depends on existing agricultural diversity and market access (60, 61), our results suggest that production and dietary diversity are related in this population. Sustainable agriculture practices also increased significantly and by a large magnitude. For example, at baseline, only 5.7% of households intercropped; exposure to SNAP-Tz increased this by 42.6 pp. This is comparable to the effect observed in an agroecology intervention in Malawi, in which intercropping increased from 29% to 93% (27).

SNAP-Tz increased women's relative power in income allocation decision making but not in agricultural decisions (Figure 5). These results are consistent with what has been observed in other NSA interventions (53, 57). It is possible that this increase in power contributed to the observed improvement in the dietary diversity of children, but such a claim must be made cautiously. The baseline value for this outcome was low (0.36), and it is unclear whether the observed increase (0.07 on a 0–1 scale) was sufficient to alter income allocation decision making in a meaningful way. SNAP-Tz increased the empowerment score according to A-WEAI by 0.15 points. This was driven by increases in the scores for the group membership domain because participation in SNAP-Tz meant that one had joined a group (Supplemental Figure 9).

SNAP-Tz did not cause women to spend more time on household tasks and child care (Figure 5). This is encouraging because NSA interventions have been criticized for increasing time burdens on women (62). It is noteworthy that the intervention increased men's involvement in household activities by 0.36 tasks. However, because there are currently no other studies that assessed the impact of NSA on men's involvement in household work and child care to which we can compare our results, it is not clear whether the magnitude of this impact on male involvement is meaningful.

In terms of the impacts on women's well-being that we measured, we found that the intervention increased the proportion of women achieving the MDD by 15.2 pp. Other NSA studies that have reported impacts on women's nutritional intake either report no statistically significant impacts on MDD (56) or report impacts on the number of food groups consumed but not on MDD (57, 63). The proportion of women reporting adequate social support increased by 13.3 pp (Figure 6B), and the proportion of women with probable depression was reduced by 11.6 pp (Figure 5). The effect size on depression is large; for example, a participatory women's group intervention whose primary outcome was to reduce depression found a similar-sized impact (64). To our knowledge, this is the first NSA intervention, agroecological or otherwise, that has documented an impact on women's mental health.

Our study has a number of strengths, including randomization of the intervention to reduce the risk of confounding, adequate power, and sufficient duration of implementation. We also collected and analyzed a wide range of data, allowing us to assess—in addition to the primary and secondary outcomes listed in our trial registry—impacts on dimensions of sustainable agriculture as well as women's empowerment and well-being. Limitations include that we did not measure legume yield or household income, which would have allowed for analysis of the income pathway by which children's diet and anthropometric indicators may be shaped, nor do we have data on impacts on soil health. We did not measure indicators of men's empowerment and well-being, which limits our ability to analyze these outcomes. Furthermore, in any cluster-based

randomized control trial, there is a risk of spillover from intervention to control localities, which would bias our results toward null impact. Although we cannot test for this formally, field staff observed minimal interaction between individuals living in intervention and control villages. Our analysis relies heavily on self-reports, which makes our results vulnerable to social desirability bias. We took precautions to address this by avoiding leading questions, using different personnel for enumeration and intervention implementation, and assurance of “no wrong answers” throughout the survey. We also measured social desirability bias in July 2018 and found that it was both low and nondifferential between study arms (Supplemental Text 2 and Supplemental Table 9). However, because we did not measure social desirability bias at baseline, we are unable to adjust for it. Finally, we are reluctant to make strong claims about external validity. SNAP-Tz was implemented in only 1 rural area of Tanzania using an agroecological focus tailored to that region.

In summary, SNAP-Tz, a nutrition-sensitive agroecological intervention, improved the diets of children and improved household food security but did not improve child anthropometric outcomes. It also led to improvements in sustainable agriculture practices and indicators of women’s empowerment and well-being, and the intervention achieved all this through the provision of relatively minimal inputs. As such, this study advances our understanding of NSA by demonstrating that such an approach can work when using agroecological practices. This study also advances our knowledge of agroecology interventions by providing evidence of impacts on nutrition and well-being generated using a rigorous study design and empirical methods. These results point to the potential for nutrition-sensitive agroecology interventions to improve indicators relating to sustainable agricultural practices, women’s empowerment and well-being, household food security, and children’s dietary diversity.

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authors: critically reviewed multiple drafts of the paper and read and approved the final manuscript.

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