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Research paper

Is seed aid distribution still justified in South Sudan?

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ABSTRACT

Seed aid—or free distribution of seeds to farmers—is a popular intervention to simultaneously reduce food insecurity and dependency on food aid in fragile countries. However, seed aid distribution also has the potential to hinder or distort the development of local seed markets. In this study we analyze the targeting and impact of seed aid across the green belt (cutting across the southern/equatorial states) of South Sudan. Using a primary and unique dataset on 1,990 farm households, we find that seed aid is widely rather than selectively distributed. Almost a third of farm households receive seed aid despite the general availability of locally recycled seed varieties. Seed aid distribution does not seem to favor particularly poor, vulnerable and food insecure households, but those that are embedded in community networks, organizations and institutions. Using a double robust methodology based on Inverse Probability Weighted Regression Adjustment (IPWRA), we also find that the adoption of seed aid by farm households does not result in increased maize production, as it is neither associated with agricultural intensification nor with the expansion of cultivated land. Seed aid seems to substitute rather than supplement local seed varieties. These findings emphasize a lack of intentionality in seed aid distribution. Still, it must be noted that the effectiveness of seed aid distribution may be greater outside our study area, above the green belt, where conflicts and natural disasters remain more frequent and intense, and where farmers are more likely to be seed insecure. But overall, this study supports the widespread perception that South Sudan is ready for a transition towards a market-based seed distribution system.

1. Introduction

Farmers require timely access to seeds to grow food, to earn a living and contribute to their own and others' food security. In a functioning agricultural sector, farmers can access seeds by recycling their own agricultural output; through exchanges with other farmers; or through the market (Louwaars and De Boef, 2012). In fragile countries characterized by recurrent conflicts and disasters, farmers may experience insecure access to seeds, justifying the distribution of seed aid by intergovernmental and non-governmental humanitarian agencies. The Food and Agricultural Organization of the United Nations (FAO) spends almost one billion US dollars per year in emergency and resilience operations, which are in most instances involving the distribution of seed aid.[1] Reportedly, the distribution of seed aid has the potential to alleviate food insecurity by revitalizing agricultural production and reducing dependency on food aid. While data on seed aid is scant, there is evidence suggesting that seed aid is becoming more important in an increasing number of countries and is even extending to non-fragile areas (Sperling et al., 2020). Sub-Saharan Africa has a particularly long history of seed aid and subsidization as a policy to stimulate agricultural development, both before and after the market liberalization period in the 1990 s (Holden, 2019; Mason et al., 2013; Sperling et al., 2020).

While seed aid is often regarded as a valid approach to limit dependency on food aid and restore agricultural resilience, its actual effects remain understudied (Sperling and McGuire, 2010). There is particular concern that seed aid might hinder or distort the development of local seed markets (see e.g., Sperling and McGuire, 2010; Tripp and Rohrbach, 2001). In particular, the distribution of free seeds that are procured internationally has the potential to hinder or distort local seed production and commercialization. This implies that seed aid should be seen as a temporary fix that is justified only in the presence of an acute

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emergency leading to seed market failure and seed insecurity. But in reality, emergencies can become chronic situations that favor the unintentional institutionalization of seed aid systems over time. As such, the main challenge is to understand when seed aid is justified, and when it is not.

We attempt to address this general question by investigating the impact of seed aid distribution on South Sudan's agriculture. South Sudan is considered a fragile country since it came into existence in 2011, with internal conflicts flaring up on a regular basis until this day. It is also a large recipient of seed aid, with an estimated 40 percent of the farm households having received seed aid at least once (FAO et al., 2019). At the same time, South Sudan is witnessing the rise of seed sector development interventions (FAO et al., 2019). This makes it a relevant and suitable country to study how seed aid is distributed to farmers and its impact on agricultural production.

We investigate the justification of seed aid in South Sudan using baseline data of the A3SEED project, which were collected by the authors of this paper.[2] The latter project aims at strengthening quality seed production and commercialization by South Sudanese seed companies and their networks of local outgrowers and agrodealers. The authors of this paper are involved in this project as independent impact evaluators. The dataset was collected at the end of 2021 and captures data on 1,990 farmers from five counties within the green belt of South Sudan: Yambio, Nzara, Magwi, Torit, and Juba. These counties were relatively stable and peaceful and generally considered as high agricultural potential areas, by the time we carried out our survey. The available data show that farmers in these areas are receiving seed aid and are also recycling their own seeds, but they are buying a negligible amount of seeds from the market.

Our analysis suggests that seed aid is widely distributed within the sample, reaching almost a third of surveyed farmers. We also find that seed aid is widely rather than selectively distributed. Vulnerability indicators, such as food insecurity, internal displacement, and asset poverty are only weakly related to the adoption of seed aid by farm households. More important determinants of seed aid adoption are related to a farmer's social network, such as: membership of cooperatives and other community-based organizations, being a village leader, and owning a mobile phone. Using inverse-probability-weighted regression adjustment (IPWRA), we find no evidence that freely distributed seed is resulting in larger maize production, higher yields or to an expansion of cultivated land. Our findings thus suggest that seed aid distribution does not generate significant benefits for farmers, except for those who would otherwise have no access whatsoever to seeds (not even to recycled local varieties). And because seed aid is largely sourced from outside South Sudan, it is also likely to hinder or distort the development of the domestic seed market.

As such, this paper fills two important gaps in the development literature. First, it provides primary data on, and an empirical analysis of the agricultural sector of South Sudan, which is a particularly understudied country. Second, it sheds light on the impact of seed aid distribution. Our results are in line with a related and bigger strand in the literature that has focused on the effectiveness of the second generation of input subsidization programs in Africa in the early 2000 s (e.g., Dorward 2009; Jayne and Rashid, 2013; Jayne et al. 2018; Hemming, et al., 2018; Holden, 2019). This literature looks at the effects of distributing fertilizer and seeds below market rates—as opposed to free of charge—and is largely situated in non-fragile settings. However, the mechanisms and incentive effects can be expected to be similar. It finds that subsidies can increase input use, agricultural yields and income among farm households, but that the design of the subsidy scheme—including its targeting—and the context in which it is implemented—including the availability of inputs—is crucially important for its effectiveness (Hemming et al., 2018). Moreover, general equilibrium welfare and total food production effects are smaller than typically expected due to crowding-out of commercial seed and fertilizer sectors (e.g., Mason and Ricker-Gilbert, 2013; Mason et al. 2013; Ricker-Gilbert et al., 2011; Jayne et al. 2013; Jayne et al. 2018; Xu et al. 2009).

Our work also relates to the literature on food aid, which mostly occurs in fragile settings. Economists have long expressed the concern that food aid could reduce food prices and incentives for farmers to produce (more) food (e.g., Schultz 1960). While earlier case studies confirmed this (Abdulai et al., 2005), more recent and careful empirical work finds that such concerns were largely unwarranted (see e.g., Abdulai et al., 2005; Gautam, 2019; Margolies and Hoddinott, 2012). Also for food aid, however, proper targeting of the most vulnerable households remains key prerequisite for effectiveness (Barrett 2002). The dearth of empirical research on seed aid relative to these other two forms of aid might be explained by the fact that: a) seed aid is often provided in regions with low levels of security impeding in-depth empirical research, whereas fertilizer and seed subsidies are more common in stable regions; and b) research on seed aid requires detailed farm-level data, whereas research on food aid typically relies on market level price data.

2. Background

South Sudan came in existence as an independent country in 2011 following a popular referendum that legitimized its secession from Sudan. The years that followed were characterized by political instability and economic stagnation, leading up to internal, violent and country-wide conflicts in 2013 and 2016. Despite a revitalization of the peace agreement in September 2018 and the subsequent formation of a unity government in February 2020, South Sudan remains a country in turmoil and in the making. Due to extreme climate events (both droughts and floods), underdeveloped infrastructure, persistent insecurity and weak economy, 8.3 million people (or 75 % of the population) were estimated to face severe food insecurity in 2022 (World Food Programme, 2022). Furthermore, 2.2 million people were estimated by IOM to be internally displaced at the end of 2021.

Despite the abundance of land and favorable agro-ecological conditions, agriculture in South Sudan—the most important national economic sector after oil—remains largely underdeveloped. The most important staple crops include sorghum (throughout the country) and maize (mainly in the Equatoria states). The area under cultivation is constrained by the lack of mechanization and total production is further subdued due to the use of basic farm technologies. As a result, most farmers produce for own consumption and commercialized surplus of food is limited. Whereas the country historically was a net exporter of grains and other agricultural products to regional markets, the country now imports as much as 50 % of its food needs from neighboring countries (African Development Bank Group, 2013).

Like the rest of the agricultural sector, the formal seed sector remains largely underdeveloped in South Sudan and access to (certified) quality seed is problematic for the large majority of farmers. In fact, most of the seed is imported from Uganda, Kenya, and Sudan, under different agro-ecological conditions and different farming practices (FAO et al., 2019). Most farmers therefore rely on an informal seed system based on seed selection, production, and diffusion by non-specialized farmers. In addition, seed aid is an important channel to access seed. In the past five years, over 40 % of all farmers in South Sudan received some form of seed aid (FAO et al., 2019). The Food and Agriculture Organization of the United Nations (FAO) has played a central role in the coordination of seed aid in collaboration with the government and Non-Governmental Organizations (NGOs).

Parallel to the free distribution of seed aid, FAO and several NGOs

[2] A3SEED is an acronym for Accelerating Agriculture and Agribusiness in South Sudan for Enhanced Economic Development. The project aims to provide technical and financial support for the development of the private seed sector in South Sudan. The A3SEED project is implemented by IFDC and KIT between 2021 and 2026.

also implement projects to decrease the reliance on humanitarian assistance and develop the (semi-)formal seed system. Projects have, for example, contributed to the establishment of South Sudanese seed companies and the formation of a umbrella organization: "the Seed Trade Association of South Sudan" (STASS). Other ongoing projects focus on supporting these companies to increase local production of quality seeds, and the marketing of these seeds to farmers and to humanitarian agencies.

3. Materials and methods

This section describes the quantitative data we gathered and analyzed for this study, collected through a farm household survey. Data collection took place between September and December 2021 in five counties across Western, Central, and Eastern Equatoria states: Yambio (N = 501), Nzara (N = 500), Juba (N = 65), Magwi (N = 722), and Torit (N = 194). This sample was intended to be representative of the population of farm households targeted by the A3SEED project across the green belt of South Sudan. In particular, the population targeted by the project comprises smallholding farmers that are expected to be potential buyers of certified seeds. The total sample size is 1990 farm households. The sample size for each of the counties was set in proportion to the size of the target population. Villages were randomly selected in each county. Within each village, a random sample was drawn from lists of farm households provided by village leaders and local authorities.

Farm households were interviewed on their two most important crops for income generation purposes, based on their own perception. Maize was identified as the most important crop by 1329 farmers (or 67 % of farm households). The other crops identified as "most important" were sorghum (N = 234), groundnut (N = 918), cowpea (N = 48), beans (N = 152), millet (N = 9), and rice (N = 90). To comply with county-specific cultures and languages, all enumerators were locally recruited and conducted interviews only in their counties of origin. All enumerators received a three-day training on the questionnaire and data collection approach, right before the beginning of field work.

Table 1 presents the basic characteristics of the farm households in our sample. It describes data available for the entire sample and for a sub-sample of maize-producing farm households, given that maize was the most widely produced crop. The average farm household appears to be large, including about nine members, and to have a high dependency ratio. Throughout 2021, farm households experienced slightly more than one month of food insecurity, or inadequate food provisioning, on average. Input use appears to be very limited among maize producing farm households, which on average cultivate one to two hectares of land to produce 1,380 kg of maize, with an average productivity of 1177 kg of maize per hectare. It is important to note that FAOSTAT (2020) reports average maize yields of almost 2000 kg/ha in Kenya and almost 3000 kg/ha in Uganda. The average share of maize production that is sold is estimated at 42 percent. This means that most of the maize produced by a farm household (58 percent) is used to satisfy its own consumption needs.

Table 1 also indicates that 26 percent of the farmers have received seed aid for at least one of their crops during the past agricultural season (2021). Fig. 1 shows the variation in seed aid distribution by crop and county. Seed aid is mostly provided for staple crops, such as maize and sorghum. For both these crops, 27 percent of the households received relief seed. A smaller share (13 percent) of the households received free groundnut seeds. The distribution of seed aid was more concentrated in the capital Juba and nearby counties of Magwi and Torit. The quantity of seed aid received by the average farm household was 11.5 kg for maize, which is roughly sufficient to cultivate one *feddan* (or acre) of maize. Sorghum farmers received 10.5 kg of free seeds on average, which allows to cultivate a bit more than one hectare. The dominant variety of freely distributed maize seeds was the Longe5, which is an open-pollinated (as opposed to hybrid) variety developed more than 20 years ago by the National Agricultural Research Organizations of Uganda. In terms of seed types, little variation was found. All households (those receiving seed aid and those not receiving seed aid) made use of open-pollinated and local varieties, and generally recycled these seeds for long periods of time. In fact, only 1.5 % of the sample indicated to have purchased seeds from the market, and less than 1 % of the sample indicated to have used hybrid varieties.

Table 1
Household characteristics.

	Full sample Mean (Std.Dev.)	Maize farmers Mean (Std.Dev.)
Household received seed aid in 2021 (yes/no)	26 % (44 %)	27 % (44 %)
Vulnerability:		
Displaced household (yes/no)[3]	4 % (20 %)	5 % (21 %)
Number of months of adequate household food provisioning (min = 0; max = 12)	10.8 (1.2)	10.9 (1.1)
Number of shocks experienced by the household	2.22 (1.8)	2.28 (2.2)
Asset:		
Tenure security (yes/no)	71 % (46 %)	73 % (44 %)
House ownership (yes/no)	94 % (23 %)	96 % (19 %)
Motorbike ownership (yes/no)	29 % (45 %)	32 % (47 %)
Radio ownership (yes/no)	50 % (50 %)	55 % (50 %)
Land holdings (hectares)	2.30 (3.1)	2.48 (3.1)
Household head is educated beyond primary school (yes/no)	33 % (47 %)	34 % (47 %)
Social network:		
CBO membership (yes/no)	59 % (49 %)	61 % (48 %)
Households regularly visits religious house (yes/no)	83 % (38 %)	84 % (38 %)
Village leader (yes/no)	24 % (43 %)	22 % (43 %)
Mobile phone ownership (yes/no)	36 % (46 %)	37 % (46 %)
General characteristics and fixed effects:		
Children in school (yes/no)	81 % (39 %)	80 % (39 %)
Household size	8.7 (4.7)	9.0 (4.8)
Dependency ratio[4]	74.4 (77)	72.1 (71.1)
Household head is young (age < 35; yes/no)	38 % (48 %)	39 % (49 %)
Household head is female (yes/no)	29 % (45 %)	25 % (45 %)
County of residence = Juba	3 % (18 %)	2 % (17 %)
County of residence = Yambio	25 % (43 %)	23 % (43 %)
County of residence = Nzara	25 % (43 %)	30 % (45 %)
County of residence = Torit	10 % (29 %)	3 % (18 %)
County of residence = Magwi	36 % (48 %)	42 % (49 %)
Maize-specific indicators:		
Input use: fertilizer (yes/no)	/	1 % (9 %)
Input use: pest-management[5] (yes/no)	/	9 % (12 %)
Land under maize cultivation (ha)	/	1,59 (1.6)
Maize production (kg)	/	1380 (2215)
Maize productivity (kg/ha)	/	1177 (1708)
Share of maize harvest sold (%)	/	42 % (27 %)
Number of observations	*1990*	*1461*

[3]Includes households that were displaced or returned to their communities within the last three years.
[4]The dependency ratio is calculated by dividing the number of dependent household members (those under the age of 15 and above the age of 65) by the total number of household members.
[5]This includes the use of insecticides, herbicides and fungicides.

4. Results

This section presents and discusses a two-step analysis of available data, which is geared to better understand how seed aid is targeted in practice—or which typology of farm households are most likely to receive seed aid—and to assess the effect of seed aid on maize production.

4.1. Targeting of seed aid

We run a Probit regression to identify key factors explaining whether a farm household received seed aid in 2021, or not. Our model includes four categories of explanatory variables, which are assumed to be

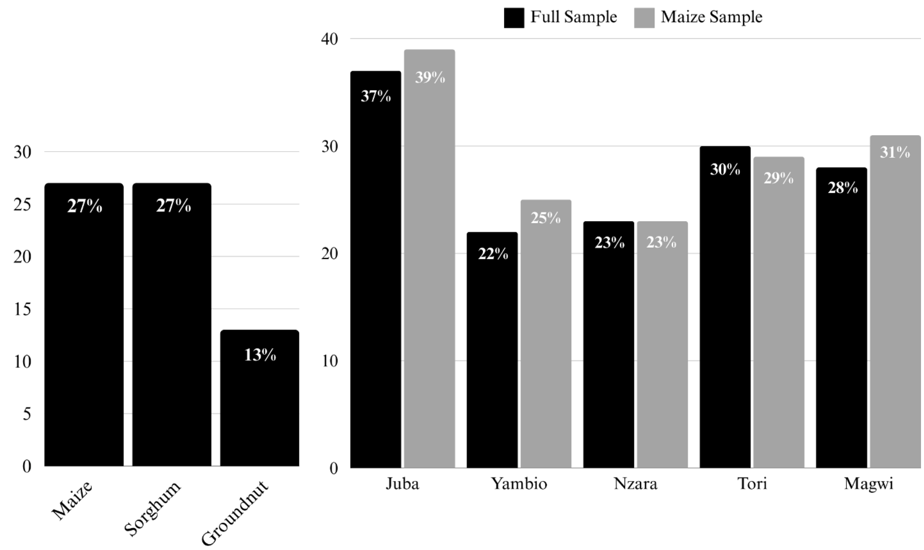

Fig. 1. Percentage of households receiving seed aid, by crop and county.

exogenous and to explain the likelihood for a farm household to receive seed aid.

The first category of explanatory variables is specified to capture vulnerability: whether farm households were a) displaced or returned to their original location during 2021; b) exposed to livelihood disrupting shocks of any kind during 2021; or c) affected by food insecurity before the start of the 2021 main planting season. We expect seed aid to be targeted to particularly vulnerable households and therefore we expect these variables to have positive and significant coefficients. The second category includes proxy variables for a farm household's social network: a) whether the head of a farm household is a village leader, a member of at least one community-based organization (CBO), a regular visitor of a religious house, and/or the owner of a mobile phone. We also expect these variables to have positive coefficients, as social networks or connections have the potential to increase the farm households' access to seed aid. The third category focuses on household assets, measured on the basis of land holdings and rights, attained education level, house ownership and ownership of other assets (motorbike and radio). We expect negative coefficients for these variables, since we expect asset poor households to be a more likely target for seed aid. Finally, the model specifies also a few variables capturing general farm household characteristics and fixed effects (or location specific effects).

Table 2 presents the results. In line with Fig. 1, location is an important determinant for receiving seed aid. Farm households in the relatively central counties of Juba and Torit are more likely to have received seed aid than farm households in the more remote counties of Magwi, Nzara, and Yambio. In addition, displaced or returning households were more likely to receive seed aid. However, other vulnerability indicators, such as food security and exposure to shocks, and being asset poor are not significant in explaining access to seed aid. More important and significant is the combined predictive power of proxy variables for a household's social network. Being a CBO member, visiting a religious house, being a village leader, and owning a mobile phone are all associated with significantly higher likelihood to receive seed aid.

Although being internally displaced makes it more likely for a household to receive seed aid, it is still unclear how well the seed aid is targeted to these internally displaced households. Fig. 2 shows the number of displaced and non-displaced households that received seed aid. While 40 % of the IDPs or returnees were provided with seed aid, about 60 % of them did not receive it. Moreover, also 24 % of the non-displaced households received seed aid. Since the number of non-displaced households is considerably larger, a large share of the seed aid ends up with households that do not seem to match any specific inclusion criteria.

Table 2
Probit regression results: probability of receiving seed aid.

VARIABLES	Coefficient (Robust Standard Error)
Vulnerability:	
Displaced household	0.314 (0.153) **
Number of shocks experienced by the household	−0.014 (0.018)
Months of adequate food provision before planting season	−0.029 (0.044)
Social networks:	
CBO membership	0.338 (0.078) ***
Households regularly visits religious house	0.262 (0.096) ***
Village leader	0.187(0.074) **
Mobile phone ownership	0.061 (0.029) **
Assets:	
Asset index[6]	−0.024 (0.024)
Land owned (ha)	0.004 (0.010)
Household has land rights	−0.064 (0.081)
Household characteristics and fixed effects:	
Household size	0.009 (0.007)
Children are attending school	0.025 (0.085)
Dependency ratio	0.001 (0.000)
Household head age < 35	−0.018 (0.067)
Female-headed household	−0.087 (0.075)
Household head is educated beyond primary school	−0.068 (0.072)
County = 2, Yambio	−0.578 (0.192) ***
County = 3, Nzara	−0.499(0.182)***
County = 4, Torit	−0.162 (0.192)
County = 5, Magwi	−0.444(0.180) **
Constant	*−0.530 (0.356)*
Pseudo R^2	*0.0325*
Wald chi^2	*70.17(***)*
Observations	*1,955*

*Robust standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.*
[6]We use an asset index, created through a Principle Component Analysis. The following variables are included in the index: house ownership, access to electricity, motorbike ownership, radio ownership and the ownership of smaller assets (chair, table).

4.2. Impact of seed aid

This second analysis assesses the effect of seed aid on agricultural production, and more specifically on maize production. To do so, we considered only farm households that identified maize as their main

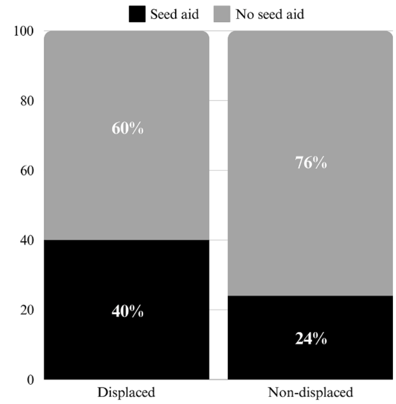

Fig. 2. Number of households receiving seed aid, by residential status.

crop and that actually produced some maize during 2021.

Our analysis proceeds in assessing changes in maize production that are attributable to farmers' utilization of seed aid as opposed to locally recycled and market-sourced seed varieties. According to our data, commercial seed varieties available at local markets are rarely purchased and used by sampled farmer households—only 3 % of the farm households indicated to make use of these seeds. Their effect on maize production can thus be considered as negligible and our analysis can therefore be considered a comparison of the use of seed aid versus the use of locally recycled seed varieties.

We estimate the effect of seed aid on three outcome indicators: i) total maize production, in kg of maize produced per farm-household ii) maize productivity or yield, measured in kg of maize produced per hectare; and iii) total size of land cultivated with maize, in hectares. Since freely distributed seeds are supposed to go through quality control and certification processes, they are expected to have higher germination rates than local seeds, whose high yielding traits tend to be lost as a result of non-scientific and non-professional seed selection (or recycling) over time. Farmers receiving seed aid are therefore assumed to have larger harvests, due to either higher yields or by allowing seed constrained farmers to cultivate a larger portion of their land.

These effects are estimated using inverse-probability-weighted regression adjustment (IPWRA) (Wooldridge 2010; Manda et al., 2018). This doubly-robust method allows for the estimation of a treatment effect on the treated by combining inverse probability weighting with a multivariate ordinary least squares (OLS) regression model. Both models specify the same set of covariates (X) to control for potential selection bias. A Probit model is used to predict the probability for a farm household to receive seed aid, and thus to compute their propensity scores $\widehat{p}(X)$. Seed aid receivers are then assigned a weight of one and those that did not receive seed aid are assigned a weight of $\frac{\widehat{p}(X)}{1-\widehat{p}(X)}$ (Hirano and Imbens, 2001). As such, this model estimates weighted differences in outcomes between seed aid receivers and non-receivers. In the OLS model, the dummy variable identifying seed aid receivers is instead specified as the main independent variable of interest to explain outcomes, ceteris paribus (or given the effects of all other independent variables). The advantage of combining OLS with inverse probability weighting, by using the inverse probability scores as weights in the regression, is that only one of the two models need to be correctly specified. However, we cannot exclude that both models are affected by some residual selection bias, or self-selection bias associated with unobserved farm-household characteristics, such as farmers' willingness to receive seed aid.

Fig. 3 shows the distribution of estimated propensity scores for seed aid receivers and non-receivers. There is sufficient overlap between the two curves, suggesting that seed aid receivers and non-receivers are indeed similar and therefore comparable, with regard to observed farm household characteristics (X). Seed aid receivers only had a slightly higher probability of receiving seed aid, and only one farm-household was not included in the estimation, because it fell outside the common support area. The Probit regression results that are used to calculate the propensity scores are included in the Appendix.

Results of the IPWRA estimation are presented in Table 3. We do not find a statistically significant difference in the total amount of maize produced between households that received seed aid and otherwise comparable households that did not. Furthermore, there is no evidence that seed aid boosts the amount of land under maize cultivation, suggesting that seed access, in our sample, was not constraining the expansion of maize cultivation. Finally, we find no significant difference in maize productivity between farm households that received seed aid

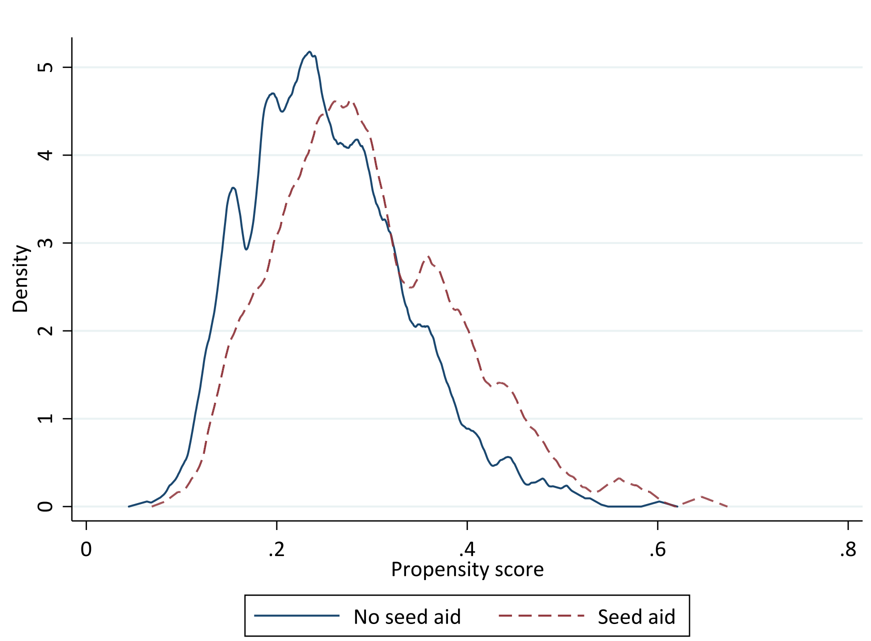

Fig. 3. Density plot of propensity scores.

Table 3
Average treatment effects on the treated (ATET).

Outcome indicators	Treatment status		ATET
	Non-receivers	Receivers	
Maize productivity (kg/ha)	1155.9 (55.50)	1222.9 (80.38)	95.42 (107)
Maize production (kg)	1312.4 (47.69)	1528.1 (143.55)	257.2 (196.9)
Land under maize cultivation (ha)	1.57 (0.048)	1.62 (0.061)	0.078 (0.074)
Observations	909	326	1235

*Robust standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$*[7].
An over-identification test for covariate balance, shows a balance in covariates (*$Chi^2 = 17.17$, $p = 0.7006$*).
[7]P-values were 0.370, 0.153 and 0.289 for maize productivity, maize production and land under maize cultivation, respectively.

and those that did not, suggesting that the imported seed varieties that are freely distributed are not higher yielding than locally recycled varieties.

In Table 4, we check the robustness of our results by running alternative propensity score matching models (with different matching algorithms) and naïve comparisons based on t-tests and unweighted OLS regression. We also test an alternative or over-specification of our IPWRA model, which included additional variables that were not clearly exogenous, such as the extent to which farmers use other inputs (i.e. fertilizer and pesticides). All these alternative estimations resulted in very similar findings to those results presented in Table 3.

5. Discussion

Our data shows that international seed aid is distributed on a large scale across the green belt of South Sudan, reaching almost a third of local and semi-subsistent farm households. Internally displaced households and returnees are slightly more likely to receive seed aid, but other vulnerable households, affected by shocks and food insecurity, do not seem to have better access to seed aid. Instead, a farmer's social network appears to be the most important factor. Farmers who are village leaders, members of community based organizations and religious congregations, as well as owners of mobile phones are significantly more likely to receive seed aid. As such, our data suggest that seed aid distribution is not selectively targeted towards those most in need of seeds, but it rather reaches those that are better connected.

In addition, we find that freely distributed seeds do not contribute to the intensification nor the expansion of maize production. This means that the international seeds distributed by aid agencies substitute rather than complement local reserves of recycled seeds, with no major implications in terms of overall seed quality.

These findings suggest an apparent lack of intentionality in the seed aid system, As such, seed aid might also reduce the demand for seeds produced by a formal seed system, as seed aid is particularly accessible for farm households that are well connected and that already have access to seeds through other channels.

It is important to recognize that the validity of these conclusions has both internal and external limitations. First of all, our study was confined to the green belt of South Sudan, and did not take into account farm households that would have liked to produce maize, but could not to do so because they had no access whatsoever to any kind of seeds. Instead, we reasonably assumed that seed aid distribution in other and less favored parts of the country and to seed-deprived farmers results in a positive impact. By doing so, we inevitably limited the external validity of our analysis and conclusion to maize farmers with access to seed through the market or through seed aid. Secondly, we have not analyzed the counterfactual of there not being any seed aid available in the country. The general equilibrium effects of seed aid on seed availability and seed prices, for instance, are not taken into account.

Overall, this study firmly supports the idea that South Sudan is ready for a transition towards a market-based seed distribution system. This should go hand-in-hand with the introduction of better targeted and less disruptive seed aid in those areas where there are still seed shortages. A promising alternative for unselective and free seed distribution could be the introduction of e-vouchers that could simultaneously make seed aid better targeted towards seed-deprived farm households, while simultaneously stimulating the domestic seed market.

CRediT authorship contribution statement

Esther Smits: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Rob Kuijpers:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Formal analysis, Conceptualization. **Justin Amos Miteng:** Validation, Funding administration. **David Deng Chol:** Resources, Investigation. **Turo Thomas Mono:** Resources, Investigation. **Nicola Francesconi:** Writing – review & editing, Validation, Supervision, Project administration, Methodology, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: [All authors declare not to have any personal interest in the topics discussed and recommendations given in this research. The paper is written using data collected as baseline assessment for the A3-SEED project in South Sudan, which is implemented by IFDC with technical assistance from KIT. The project is funded by the Embassy of the Kingdom of the Netherlands in South Sudan. The funder of the project has in no way been involved in decisions around this research paper. Esther Smits, Rob Kuijpers and Nicola Francesconi are involved in the independent evaluation of the project. They have taken the lead in the analysis and writing of this study. Justin Amos Miteng is leading the project on behalf of IFDC; David Deng Chol and Turo Thomas Mono are involved in the monitoring and evaluation of the project on behalf of IFDC. They have been involved in the collection of the data, and the provision of critical feedback as experts in the field.].

Data availability

Data will be made available on request.

Table 4
Robustness checks.

Outcome Indicators	ATET estimated through different techniques				
	PSM One-to-one matching	PSM Kernel matching	Naïve T-test	Naïve OLS	IPWRA Alternative specification
Maize productivity (kg/ha)	133.9 (91.8)	87.6 (105.3)	21 (109.6)	86.7 (102.9)	79.0 (94.8)
Maize production (kg)	339.8 (207.6)	332.0 (203)	216 (142)*	248.7 (180.3)	210.7 (150.6)
Land under maize cultivation (ha)	0.038 (0.08)	0.05 (0.10)	0.17 (0.097)**	0.067 (0.071)	0.059 (0.064)
Observations	*1,236*	*1,236*	*1,236*	*1,236*	*1,258*

*Robust standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.*

Appendix

Table 5 Covariate balance summary.

Covariate balance summary			Raw	Weighted
		Number of obs	1,235	1,235
		Treated obs	326	618
		Control obs	909	616
	Standardized differences		Variance ratio	
	Raw	Weighted	Raw	Weighted
Tenure security	−0.113	0.003	1.128	0.996
Number of months of adequate household food provision	0.077	−0.001	0.899	1.027
Household head age < 35	−0,005	0.012	0.999	1.001
Household head is female	−0.096	0.022	0.894	1.024
CBO membership	0.170	−0.123	0.911	1.005
Household size	0.055	0.0119	1.409	1.259
Dependency ratio	0.173	0.010	1.567	1.068
Religious household	0.141	−0.000	0.755	1.000
Village leadership	0.179	−0.002	1.250	0.996
Household head is educated beyond primary school	−0.013	−0.002	0.993	0.998
House ownership	0.061	0,0197	0.726	0.903
Mobile phone ownership	0.010	−0.003	1.518	1.241
Motorbike ownership	−0.037	−0.027	0.974	0.990
Radio ownership	−0.090	0.010	1.021	0.997
Children in school	−0.009	−0.009	1.016	1.014
Land owner (ha)	0.071	0.004	1.386	1.103
County = Juba	0.095	−0.002	1.736	0.985
County = Yambio	−0.045	−0.006	0.945	0.992
County = Nzara	−0.133	0.026	0.904	1.019
County = Torit	0.007	−0.027	1.046	0.846

Table 6. Overidentification test for covariate balance.

Overidentification test for covariate balance	
H0: Covariates are balanced:	
Chi2(21)	17.1724
Prob > chi2	0.7006

Table 7. Probit model estimates of treatment status, maize sample.

Variables	(1)
Household has land rights	−0.118 (0.0938)
Months of adequate food provision before planting season	0.0689 (0.0582)
Household head age < 35	−0.0408 (0.0779)
Female-headed household	−0.1282 (0.0900)
CBO membership	0.323*** (0.0854)
Household size	0.0074 (0.00883)
Dependency ratio	0.0011** (0.0005)
Households regularly visits religious house	0.307*** (0.112)
Village leader	0.1968** (0.088)
Household head is educated beyond primary school	−0.0508 (0.0823)
Phone ownership	0.0712** (0.0332)
Asset index	−0.0355 (0.0279)
Children are attending school	−0.087 (0.0956)
Land owned (ha)	−0.0025 (0.0121)
County = Juba	–
County = Yambio	−0.609 (0.243)**
County = Nzara	−0.539 (0.232)**
County = Torit	−0.247 (0.299)
County = Magwi	−0.437 (0.233)*
Constant	−1.026** (0.468)
Observations	1,313

Table 8. Naïve OLS regression used as robustness check.

	(1)	(2)	(3)
VARIABLES	Maize yield (kg/ha)	Total maize production (kg)	Land for maize cultivation (ha)
Seed aid (y/n)	86.68	248.7*	0.0666
	(105.9)	(139.8)	(0.0689)
Household has land rights	178.9	456.7***	0.143*
	(120.9)	(159.5)	(0.0778)
Months of adequate food provision before planting season	−264.7***	−57.01	−0.0666
	(75.40)	(99.51)	(0.0475)

(continued on next page)

(*continued*)

	(1)	(2)	(3)
Household head age < 35	−172.4*	−252.0*	−0.00763
	(98.35)	(129.8)	(0.0644)
Female-headed household	−7.600	−70.47	0.0149
	(114.0)	(150.5)	(0.0745)
CBO membership	−75.07	−338.2**	−0.249***
	(106.5)	(140.6)	(0.0690)
Household size	−5.320	36.44***	0.0199***
	(10.64)	(14.04)	(0.00707)
Dependency ratio	0.358	−0.442	−0.000992**
	(0.683)	(0.902)	(0.000451)
Households regularly visits religious house	200.1	161.3	−0.0658
	(135.5)	(178.8)	(0.0895)
Village leader	207.0*	378.0**	−0.0579
	(115.6)	(152.6)	(0.0763)
Household head is educated beyond primary school	−26.59	10.41	−0.0649
	(105.5)	(139.2)	(0.0693)
House ownership	121.1	204.2	0.251
	(253.6)	(334.7)	(0.161)
Phone ownership	42.55	−17.31	−0.0227
	(43.40)	(57.28)	(0.0277)
Asset index	−1.288	−7.611	0.0605**
	(36.19)	(47.76)	(0.0236)
Land owned (ha)	−27.48	126.8***	0.318***
	(17.38)	(22.93)	(0.0112)
County = Juba	−2,909***	−1,597***	
	(411.5)	(543.1)	
County = Yambio	−2,011***	−771.5*	0.236
	(318.8)	(420.8)	(0.216)
County = Nzara	−1,891***	−142.1	0.271
	(304.9)	(402.4)	(0.206)
Magwi	−2,746***	−719.8*	1.019***
	(298.5)	(393.9)	(0.207)
Torit	–	–	0.684**
			(0.267)
Constant	4,866***	1,250	0.289
	(628.8)	(829.9)	(0.419)
Observations	1,234	1,234	1,311
R-squared	0.137	0.107	0.539

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