Impact of transnational land acquisitions on local food security and dietary diversity

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Edited by B. L. Turner, Arizona State University, Tempe, AZ, and approved December 16, 2020 (received for review September 30, 2020)

Foreign investors have acquired approximately 90 million hectares of land for agriculture over the past two decades. The effects of these investments on local food security remain unknown. While additional cropland and intensified agriculture could potentially increase crop production, preferential targeting of prime agricultural land and transitions toward export-bound crops might affect local access to nutritious foods. We test these hypotheses in a global systematic analysis of the food security implications of existing land concessions. We combine agricultural, remote sensing, and household survey data (available in 11 sub-Saharan African countries) with georeferenced information on 160 land acquisitions in 39 countries. We find that the intended changes in cultivated crop types generally imply transitions toward energy-rich, but nutrient-poor, crops that are predominantly destined for export markets. Specific impacts on food production and access vary substantially across regions. Deals likely have little effect on food security in eastern Europe and Latin America, where they predominantly occur within agricultural areas with current export-oriented crops, and where agriculture would have both expanded and intensified regardless of the land deals. This contrasts with Asia and sub-Saharan Africa, where deals are associated with both an expansion and intensification (in Asia) of crop production. Deals in these regions also shift production away from local staples and coincide with a gradually decreasing dietary diversity among the surveyed households in sub-Saharan Africa. Together, these findings point to a paradox, where land deals can simultaneously increase crop production and threaten local food security.

cropland | agriculture | land deals | nutrition | food systems

An estimated 90 million hectares of arable land (approximately the surface area of Venezuela) have been purchased or leased by foreign investors since the early 2000s (1). Fueled, in part, by the 2008 global food crisis, these transnational large-scale land acquisitions (LSLAs, here also referred to as "land deals") predominantly target agricultural land in sub-Saharan Africa, Asia, eastern Europe, and Latin America, where prevailing yield gaps and land commodification allow foreign corporations or joint ventures to profit by increasing crop production (2). By replacing traditional farming with intensified agriculture, this global land rush is fueling a new agrarian transition, and leaves a lasting mark on rural landscapes and livelihoods (3, 4). Despite their potential to increase agricultural production, the overall implications of LSLAs on food systems in targeted countries are debated (4–7).

Traditional smallholder agriculture has often struggled to alleviate poverty. Chronic underinvestment in agriculture has kept yields low (8), while competition from underpriced and subsidized imports has often limited agricultural development in many of the regions that are targeted by land investors (9). However, areas that were able to adopt modern agricultural technologies experienced improvements in health outcomes (10, 11). In that context, it has been argued that LSLAs might facilitate technology transfers, intensify agricultural production, achieve economies of scale, and contribute to closing the yield gap (12), thus reducing greenhouse gas emissions (13). Efficient agricultural practices can also, theoretically, spill over to surrounding communities, along with increased access to income, capital, and global markets (14), although the capacity and capital necessary for adoption varies widely across smallholders (15). However, closing yield gaps might not necessarily alleviate smallholder farmer poverty or increase food security (6, 7). A growing number of studies in agroecology and related fields have also challenged the narrative that higher yields can only be attained by displacing and replacing smallholder farming with large-scale commercial agriculture (16–20). In addition, LSLAs are associated with a number of social and environmental consequences that can further hinder poverty alleviation and contribute to environmental damage (4, 21). For example, land deals might

Significance

Foreign investors have acquired vast tracts of land globally since the early 2000s, yet the food security implications of this phenomenon are poorly understood. The ability to close crop yield gaps through commercial agriculture must be weighed against local impacts on food access. We combine agricultural, remote sensing, and household survey data with georeferenced information on land deals to examine their implications on food production and access. Results point to a paradox where land deals simultaneously contribute to closing the global yield gap by increasing crop production, while threatening local food security by redirecting key dietary nutrients toward the export market. This trade-off between food production and food security calls into question the sustainability of current land investment practices.

Author contributions: M.F.M., G.P., M.T.N., V.R., and N.D.M. designed research; M.F.M., G.P., M.T.N., V.R., D.D.C., K.F.D., J.D., P.D., L.R., M.C.R., and N.D.M. performed research; M.F.M., G.P., M.T.N., V.R., and N.D.M. analyzed data; and M.F.M. wrote the paper.

The authors declare no competing interest.

This article is a PNAS Direct Submission.

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This article contains supporting information online at https://www.pnas.org/lookup/suppl/doi:10.1073/pnas.2020535118/-/DCSupplemental.

Published January 18, 2021.

cause agricultural production to expand and encroach on natural ecosystems, common-pool land resources, or smallholder agriculture, causing substantial losses in forest cover, wildlife habitat, ecosystem services, and rural livelihoods (22–25). Deals might also preferentially target prime land with high potential yields (26), which could exacerbate both their effect on local livelihoods and their potential to close the yield gap. However, many land investments have failed, and, in many cases, the acquired land has been left fallow, leading to no increase in production, while still displacing local users (4). Finally, local food security may be compromised by appropriating scarce water resources (27, 28), or by displacing food crops destined for local markets with biofuel production (4) or with less nutritious (and often export-bound) cash crops (5, 29).

Overall, no clear consensus emerges from the literature on the relative salience of these effects and their aggregate impact on food production and local dietary intake. A recent global analysis estimated that 300 million to 550 million people could be supported by improved yields on the acquired land, against 190 million to 370 million on the same land under current yield conditions (5). However, these estimates were based on reported deal characteristics (intended crops) and hypothesized scenarios (achievable yields), rather than empirical observations. Furthermore, the aggregate nature of the analysis (country level) overlooks the food security concerns that arise at the local level. At the level of individual deals, case studies have found decreases in the quantity and productivity of land available for food production (30), sometimes forcing farmers to encroach on previously forested land (31, 32). In other cases, small positive spillovers to local communities have been estimated in terms of technology, efficient agricultural practices, job opportunities, and access to input and output markets (14, 33). Overall, it is not clear whether and to what extent LSLAs contribute to agricultural intensification and/or expansion, and the associated impacts on local food production, rural livelihoods, and food security remain poorly understood.

To fill this gap, we consider a sample of 160 land deals obtained from the Land Matrix dataset (1), and covering an approximate area of 4.1 million hectares in 39 countries and four continents (Fig. 1*A*). All deals are georeferenced and were concluded or put in production after 2000, which allows them to be spatially and temporally matched with recent global gridded datasets on food production and (for a subset of 28 deals in 11 sub-Saharan African countries) with local survey data on household dietary diversity. We leverage this information to evaluate the implications of LSLAs on the supply and demand sides of food systems along three important dimensions. First, we test whether LSLAs preferentially target prime agricultural land. Second, we investigate whether land deals caused an expansion and/or intensification of crop production in the concerned areas, and whether these effects spilled over to the surrounding regions. Third, we assess whether land deals are associated with significant shifts toward export-bound and less nutritious crops, and the extent to which these effects have altered local diets. Although a robust literature has examined the impact of specific land deals on local food security (see, e.g., refs. 32 and 34–37), to the best of our knowledge, this is the most comprehensive global systematic evaluation of the effect of large (>200 ha) transnational agricultural land deals on local food systems.

Targeting of Prime Land

To evaluate the possibility that LSLAs preferentially target specific land characteristics, we calculate targeting ratios which compare the agricultural suitability within LSLA locations to that of country-averaged cropland (see *Materials and Methods*). Results reveal a nuanced portrait of land deals, with mixed evidence in support of the idea that LSLAs preferentially target prime agricultural lands (Fig. 1*C*). Overall, we find no compelling evidence that deals preferentially target areas with above-average biophysical crop suitability [as revealed through a climate- and soil-based suitability index (38)] or historical yields of major crops (from ref. 39). Similarly, land deals do not appear to target areas with significantly higher yield gaps (from ref. 40), where the potential for profits from improved crop production would have presumably been the largest.

In fact, we find that deal areas in Asia and Latin America tend to occur in more remote areas with lower than average market access (from ref. 41), crop suitability, and relative historical yields (Fig. 1*C*). This finding is consistent with the idea that land competition might affect the location of land deals in these regions, where a comparatively lower amount of land is available for new agricultural development (see ref. 42 and *SI Appendix*, Table S1). Our land use analysis (below) reveals that a substantial fraction of the surrounding land in Asia (25% of B1; *SI Appendix*, Table S1) and Latin America (32%) was already cultivated prior to the deals, despite a lower average proximity to market compared to other regions. This contrasts with sub-Saharan Africa, where we observe lower prior cultivation rates (8%). The comparatively weaker land property rights (e.g., refs. 43 and 44) in sub-Saharan Africa might have allowed deals to target land with higher-than-average access to markets, although not statistically significantly so (Fig. 1*C*).

We do, however, find clear evidence that deals target comparatively wetter regions that are more suitable to rain-fed agriculture (from ref. 45) than country-average cropland, particularly in Asia and sub-Saharan Africa, where the difference with country-level average is statistically significant. Crucially, however, green water resources are not necessarily sufficient to sustain the intended crops in all deal areas. In fact, previous studies have consistently associated land deals with increased irrigation requirements (27, 46, 47). For deals taking place in water-limited regions, existing irrigation infrastructure may be attractive to investors, either to be used directly or as an indication of the potential for additional irrigation development. Among sub-Saharan African deals that occur within water-limited areas (from ref. 45), we find that preexisting irrigation infrastructure (from ref. 48) is 4 times more prevalent in the deal area than in comparable water-limited croplands (Fig. 1*C*). In contrast, Latin American deals in water-limited regions tend to occur in areas with lower-than-average prevalence of irrigation infrastructure, which is consistent with our previous discussion on land competition.

Cropland Expansion

Our analysis suggests that cropland expanded by about 25% (from 832,000 to 1,037,000 hectares) in the considered land deals between 2005 and 2015, with substantial regional patterns. Deals in Asia experienced a marked (45%) relative increase in crop cover (Fig. 1*B* and *SI Appendix*, Table S1). In contrast, cropland expansion was more modest in sub-Saharan Africa (16%), where increases in heavily cultivated land (red in Fig. 1*B*) were compensated by transitions from moderate to lightly cultivated land elsewhere (blue to green in Fig. 1*B*). This latter transition is indicative of an abandonment of agricultural land and is predominantly associated with large sub-Saharan African deals (*SI Appendix*, Table S2). This finding is consistent with an increasing academic (49, 50) and journalistic (51, 52) literature documenting speculative deals that displaced local farmers without developing the land. A recent study (4) suggested that not all of the acquired land (<5% in sub-Saharan Africa, and about 20% globally) is actually put under production. Of note is that this contraction of cropland mainly concerns particularly large sub-Saharan African deals, which drive regional disparities in cropland expansion. These disparities vanish when controlling for deal sizes, and all regions exhibit a comparable

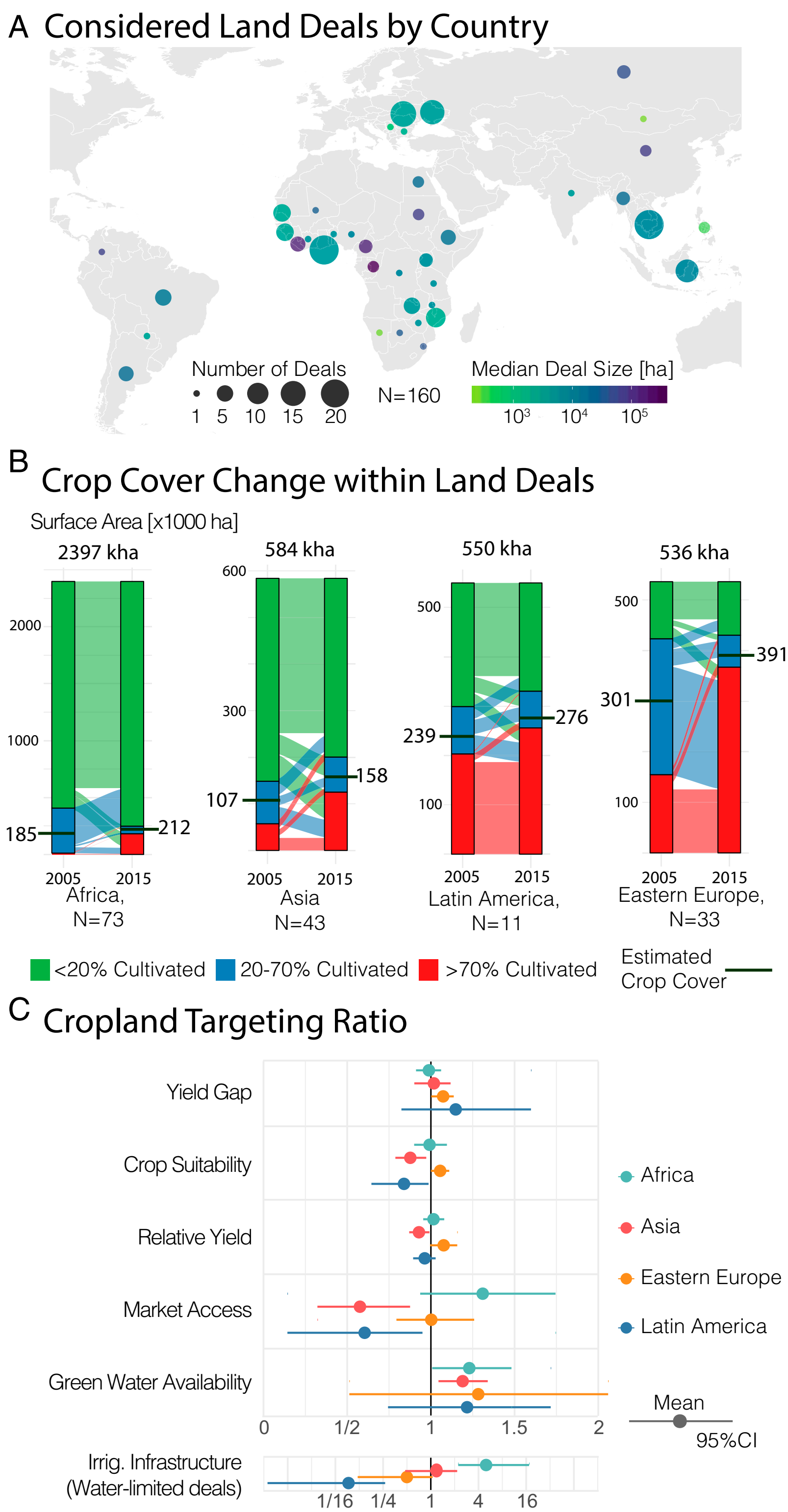

Fig. 1. (*A*) Number and median size of the considered LSLA deals by country. (*B*) Crop cover change within the considered land deals. Colored classes are given as ranges of crop cover percentages (<20%, green; 20 to 70%, blue; >70%, red) per 200-m grid cell. Numbers on top of each chart represent the aggregated surface area of the considered deals by region (in 1,000 ha). Numbered horizontal lines on the bar charts represent estimated cropland surface areas within the deals for each region in 2005 and 2015. (*C*) Preferential targeting of LSLAs. The land characteristics of LSLAs are compared to average characteristics across croplands within targeted countries using a targeting ratio. A ratio larger than one indicates that deals are targeting locations with higher values of each attribute (e.g., market access in sub-Saharan Africa). Error bars indicate bootstrapped 95% CIs around the mean (1,000 repetitions).

(about 40%; black dots in Fig. 2*B*) increase in the average fraction of cropland per deal, here referred to as "crop cover fraction" (CCF).

Because some of the detected increase in CCF would have likely occurred even in the absence of land deals, we compare it with corresponding changes in CCF within a series of control areas surrounding the acquired land at increasing distances (see *Materials and Methods* and Fig. 2*A*). This approach allows the effect of land deals to be isolated from other confounding factors (e.g., as yields, market access or local policy) that might independently affect cropland expansion (53). For this part of the analysis, we focus on the 129 land deals (153 locations) with contract dates between 2005 and 2015, which correspond to the two approximate points in time when remotely sensed crop cover estimates are available. The estimated effect of the land deals on cropland expansion can be visualized by comparing the average change in CCF within the deals (black on Fig. 2*B*) to that in the B3 control areas (farthest from the deals; light green on Fig. 2*B*) and, again, point to clear regional disparities. Land deals have a strong association with cropland expansion in sub-Saharan Africa and Asia, where a substantial proportion (50% in sub-Saharan Africa and nearly 100% in Asia) of the average increase in CCF is attributable to the deals themselves and does not occur in the corresponding control areas. In contrast, the increases in CCF observed within eastern European and Latin American deals are not significantly different from the corresponding control areas. This points to confounding factors, rather than the deals themselves, as driving cropland expansion in these regions.

Of note is that sub-Saharan Africa and Asia both exhibit gradually decreasing CCF expansions for increasingly distant control areas (B1, B2, B3, and administrative areas in Fig. 2*B*). This effect is consistent with a spillover of cropland expansion to surrounding areas outside of the acquired land, although the available data are inadequate to formally establish a causal relationship.

Agricultural Intensity

Focusing on the 129 deals with contract dates between 2005 and 2015, we observe a significant ($P < 0.05$) increase in the proportion of cropland located within 200-m grid cells with more than 70% crop cover (here referred to as "spatially dense crop fraction" [SDCF]) between 2005 and 2015 (Fig. 2*C*). This spatial consolidation of crop cover in the acquired land is indicative of a shift toward intensified agriculture. As a reality check, we also conduct a visual categorization of the deals using high-resolution satellite imagery (*SI Appendix*). A substantial portion (42%) of the deals show evidence of intensive agriculture in 2015, against 7% in 2005. About 8% of the deals also show evidence of intensive irrigation in 2015, most often on newly established commercial farms. However, the analysis in Fig. 2*C* also indicates that increases in SDCF are similar in the deal and control areas. This suggests that the spatial consolidation of cropland is unlikely attributable to the deals themselves, but rather to a background trend of agricultural consolidation that prevails in most regions. A notable exception arises in Asia, where we find a statistically significant ($P < 0.01$) excess increase in SDCF within the acquired land (Fig. 2*C*). This is indicative of a direct association between the land deals and the spatial consolidation of cropland. Similar to cropland expansion, SDCF increases in Asia are progressively less substantial for increasingly distant control areas. This is suggestive of a spillover of the effect of the deals beyond the acquired land, although the available data are inadequate to formally establish a causal relationship.

While indicative of a spatial consolidation of crop operations, SDCF does not directly measure increases in crop yields, which is a commonly used indicator of agriculture intensification. In an alternative approach, we use remotely sensed Normalized Difference Vegetation Index (NDVI) in persistently cultivated land as a proxy for biomass productivity and crop yields (as in ref. 54). A discontinuity (or change in slope) in the observed time series of (average or maximal) annual NDVI that coincides with the conclusion of a deal would be indicative of its effect on crop yields. Yet no such discontinuity is detected for deals in any of the four continents, as seen in *SI Appendix*, Fig. S4. This is consistent with the results of the SDCF analysis showing no causal association between land deals and agriculture intensification in eastern Europe, Latin America, and sub-Saharan Africa. Caution should be used in interpreting discontinuity results in Asia, where the association between NDVI and crop yields for paddy rice is known to be tenuous (54), and where the SDCF

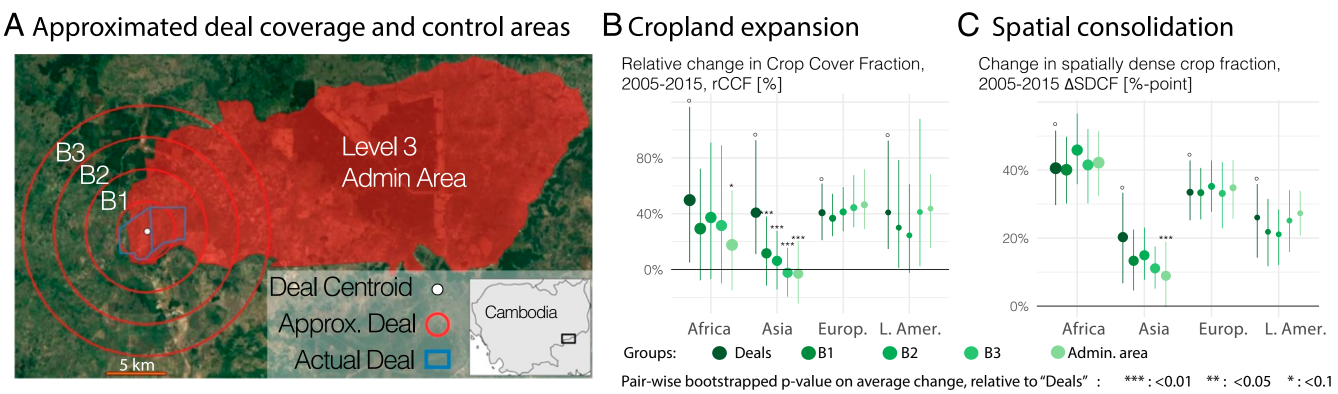

Fig. 2. (*A*) Approximated deal coverage (central red circle) and control areas (B1 to B3, red lines) for an illustrative example in eastern Cambodia. The actual deal extent is represented in blue and was obtained from the Economic Land Concessions dataset (81). The red area represents the level 3 administrative area (Commune) that contains the deal centroid (white dot). (*B*) Relative change in the CCF, defined as the fraction of land covered by crops in the deal and control areas between 2005 and 2015. (*C*) Absolute change in the SDCF defined as the fraction of cropland located in intensively cultivated land (> 70% crop cover per 300-m pixel) in deals and control areas between 2005 and 2015. In *B* and *C*, black symbols represent average changes (of CCF or SDCF) within deal areas. Symbols with different shades of greens (B1, B2, and B3) represent average change within increasingly distant control areas around the deals. Symbols with the lightest shade of green represent average change within the level 3 administrative subdivisions containing the deals. Symbol sizes are proportional to the number of deals by region. Error bars represent bootstrapped (1,000 repetitions) 95% CIs. Stars indicate bootstrapped significance levels of pair-wise differences between the deals and corresponding control areas (see *Materials and Methods*). Symbol sizes are proportional to the number of deals considered by region: sub-Saharan Africa (n = 57), Asia (n = 42), Europe (n = 20), and Latin America (n = 10).

analysis suggests an association between land deals and agriculture intensification (Fig. 2*C*).

Crop Type Transition and Dietary Diversity

Comparing crop types cultivated before the deals (*ca*. 2000; from ref. 39) with the intended crops reported in the Land Matrix reveals, again, substantial regional differences. In Asia and sub-Saharan Africa, deals are associated with transitions from local staple crops (cereals and pulses) to cash crops (sugars and oils) with a significantly higher likelihood of export (Fig. 3*B*). In terms of nutrient production, transitions in sub-Saharan Africa and Asia have led to more energy-rich, but nutrient-poor, crops after the deal (*SI Appendix*, Fig. S6). Notably, a substantial portion of deals mention palm oil and sugar cane as intended crops. Both can be planted as flex crops, meaning that they can alternatively be used for food or energy and are not a reliable source of nutrients (4, 5). About 21% of the considered deals in Asia and sub-Saharan Africa (representing 37% of the harvested land surface area) report biofuel production among their intended objectives. This suggests that our analysis likely overestimates the nutrient content of intended crops and produces a conservative estimate of the effect of land deals on nutrient production. In contrast to Asia and sub-Saharan Africa, crops cultivated prior to the deals in Latin America and eastern Europe (mainly soy and wheat) already had a comparatively high export likelihood (Fig. 3*B*). Land deals in these regions are associated with transitions toward high-value specialty crops (fruits and vegetables) and energy-rich flex crops (sugar cane), both of which remain strongly associated with the export market.

It is important to note that the above analysis is based on intended crops, as no recent comprehensive global data on crop types is available to determine observed crop type transitions. However, our findings from household surveys suggest that the expected decrease in nutrient production in sub-Saharan African land deals has materialized and cascaded through to affect local dietary diversity. We assemble a representative sample of 4,520 household clusters (here referred to as "households") from Demographic and Health Surveys (DHS) in 11 countries in sub-Saharan Africa (*SI Appendix*, Table S3). The sampled households overlap spatially with 28 of the considered deals or associated control areas (B1 to B3) and were surveyed between 2006 and 2014. Approximately half (n = 2,671) of the available households overlap spatially with two deals in Liberia and were either surveyed 2 y before (1,402 households) or 4 y after (1,268 households) their respective contract dates. In these households, and over the 2000–2014 period, we find that average dietary diversity scores [Individual Dietary Diversity Score (IDDS), ranging between 0 and 10, indicating the number of major food groups eaten within a 24-h recall period (55)] of children under 5 y of age decreased by an average of 1.19 points ($P < 0.01$; *SI Appendix*, Table S6, column 1: afterLSLA coefficient). This represents a nearly 50% decrease from a predeal average IDDS of 2.35 points. We control for a series of demographic, socioeconomic, agroecological, and geographic household characteristics known to affect dietary diversity (see *Materials and Methods*). Extending the analysis to the full dataset of 4,520 households reveals a significant (–0.35 points per year, $P < 0.01$) negative time trend in dietary diversity for households surveyed after the nearest deal was finalized (*SI Appendix*, Table S6, column 2: Year:afterLSLA coefficient), against no detectable trend for households surveyed before the deals (*SI Appendix*, Table S6, column 2: Year coefficient). The emergence of a negative dietary diversity trend concurrently with land deals is visible graphically in the nonparametric regression plot on Fig. 3*C*. The nature of DHS data (waves of cross-sectional surveys, rather than panel surveys) makes it challenging to infer a causal relationship between land deals and dietary diversity trends. However, we find that the effect is significantly smaller ($P < 0.1$) in the outermost control areas B3 (*SI Appendix*, Table S6, column 3: Year:afterLSLA:B3 coefficient), compared to households located closer to or within the approximated deal boundaries (*SI Appendix*, Table S6, column 3:Year:afteLSLA). Furthermore, we also find that deal years are uncorrelated with dietary diversity scores ($P > 0.50$ from Spearman and Kendall rank correlation tests), which makes it unlikely that the observed change in dietary diversity emerged from an unobserved time shock. These results suggest that considered land deals in sub-Saharan Africa are associated with a gradual decrease in dietary diversity among local children.

Food Production and Access

Together, our results point to general trends, and important regional disparities, in the drivers and implications of agricultural

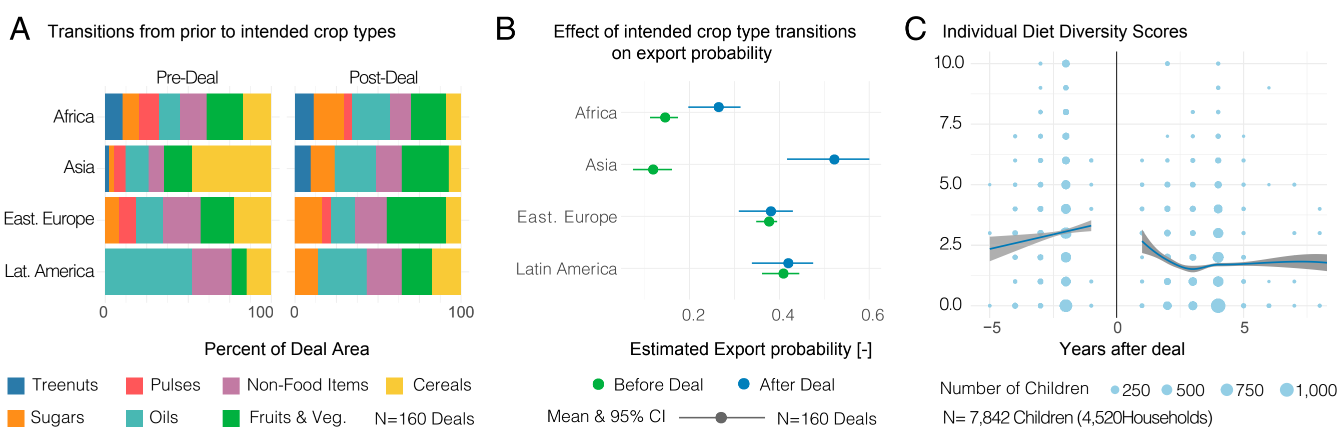

Fig. 3. (*A*) Average crop category composition of land deals by continent, before (*ca*. 2000) and after (intended crops) the transaction. (*B*) Prevalence of export-oriented crop production within LSLAs. The average likelihood of export associated with the intended crop types reported in the land matrix (blue) is compared to that of the farming systems present on the land prior to the deals (green). Corresponding results for crop nutrient production are provided in *SI Appendix*, Fig. S6. Error bars are computed by bootstrapping the 95% CI around the mean (1,000 repetitions). (*C*) Dietary diversity scores of children under 5 y of age against the number of years after the starting year of the nearest LSLA deal. IDDSs vary between 0 and 10 and were obtained from Demographic Health Surveys household clusters that spatially overlap with land deals in 11 sub-Saharan African countries (4,520 households, 7,842 individual children). Symbol sizes represent the number of children associated with each year/IDDS combination. Nonparametric regressions (locally estimated scatterplot smoothing [LOESS]) fitted independently for observations taken before (negative years) and after (positive years) the deals suggest a discontinuity and a negative IDDS trend that emerges coincidentally with land deals. Shaded areas represent LOESS 95% CIs around the mean prediction.

land deals in relation to local food systems. Three notable conclusions stand out.

First, land deals do not appear to target locations based on their biophysical suitability to crop production, with the exception of rain water availability. This finding is in line with previous results (27, 42) suggesting that water rather than land tends to drive LSLAs, but points to important regional nuances. Targeting of irrigation infrastructure is most significant in sub-Saharan Africa, where LSLAs have consistently taken advantage of property law to manipulate customary tenure property rights and legalize land dispossession and eviction of traditional and indigenous users (56). Cropland contraction observed in large sub-Saharan African deals also points to opportunistic and speculative investments. In contrast, in Asia and Latin America, where antecedent crop cover is higher and traditional land property rights are less vulnerable (43), land competition appears to affect deal locations, as seen in lower-than-average market access (both regions) and irrigation infrastructure (Latin America) in deal locations.

Second, agricultural land deals do not always stimulate an expansion or intensification of crop production, particularly in regions where both processes are already prominent. In Latin America and eastern Europe, our analysis suggests that crop production would have both expanded and intensified, regardless of the land deals. However, our results in Asia also show that LSLAs can have a substantial effect on both the extent and intensity of agricultural land use, and that, when either of these effects arises, it often spills over to regions outside of the acquired land. When weighing purported benefits and pitfalls of LSLAs, sub-Saharan Africa stands out. There, land deals have increased the prevalence of cultivated land, with the associated social and environmental displacements that have been documented in the region. However, with little evidence of cropland intensification specifically associated with land deals, their potential to close the yield gap in the continent is unclear. This is particularly true in light of the abandonment of agricultural land that our analysis suggests is taking place in large sub-Saharan African land deals (*SI Appendix*, Table S2).

Third, by affecting the types of crops grown on the targeted land, deals can influence the production of important dietary nutrients and their availability for local consumption. The latter effect is likely minimal for eastern Europe and Latin America, where deals are predominantly located in intensively cultivated areas with crops already destined for the export market. However, crop types associated with land deals in Asia and sub-Saharan Africa signal a significant transition away from local staples and toward energy-rich, but nutrient-poor, export-bound flex crops. These transitions have significant implications for local populations. Although limited to 11 countries (28 deals) in sub-Saharan Africa, where overlapping survey data are available (*SI Appendix*, Table S3), the household survey analysis that we present provides an examination of the effect of land deals on local dietary diversity within a large-scale cross-country study.

While providing a unique vantage point, the global scale of our analysis cannot fully account for the complex features and variability among individual land deals. For example, we rely on agricultural censuses that enumerate a finite number of crops and therefore overlook some food sources associated with traditional hunting or foraging practices, as well as the role of subsistence farming and backyard livestock production that never reaches the market. Although wild and traditional foods are included in the dietary diversity scores that we use, their relationship to the food security of households affected by LSLAs is complex and cannot be fully captured by standardized household surveys. As an illustration, households partly relying on foraged food will be more resilient to land deals causing a shift toward export-bound cash crops. However, they will be less resilient to deals causing an expansion of cropland that encroaches onto foraging grounds. Documenting these secondary effects is critical and relies on the meticulous collection of (often qualitative) primary field data. This grueling effort has produced a rich case study literature on the context-specific relationship between land deals and food security (see, e.g., refs. 32 and 34–37), to which the large-scale statistical analysis that we present is a complement, rather than substitute.

In conclusion, the above caveat notwithstanding, our results point to a trade-off between food production and access as an essential consequence of how and where land deals are currently executed. Deals in regions where cultivated crops were already export oriented (eastern Europe, Latin America) have a minimal effect on the already rapidly expanding and intensifying crop production. Conversely, deals in other regions (Asia and sub-Saharan Africa) can cause a significant expansion and intensification of crop production. The implications of the transition toward industrialized commercial agriculture in terms of closing the yield gap are uncertain. Recent findings (20, 57, 58) have cast doubts on the long-standing assumption that transitioning away from smallholder agriculture might substantially improve yields. However, we do find that the contemporary agrarian transition associated with LSLAs generally entails a displacement of traditional agriculture and a shift away from staple crops. This, according to our analysis, has dramatic repercussions on local dietary diversity. These findings suggest a fundamental paradox where LSLAs can increase crop production while simultaneously threatening local food security. This perverse contradiction happens because key dietary nutrients are taken away from local communities toward the export markets. This evident trade-off raises an urgent academic and policy question on the food security implications of large-scale land investments and calls into question the ethical grounds of current foreign land investment global patterns.

Materials and Methods

Deals and Control Areas. The location and basic characteristics of the considered land deals were obtained from the Land Matrix (1), a joint international initiative collecting data on transnational land deals since 2000. To our knowledge, this is the largest and most comprehensive existing database on the global land rush. Relying on large-scale standardized databases such as the Land Matrix invariably misses important contextual information on individual land deals, and the circumstances in which the relevant information was collected (see, e.g., refs. 59–62). Nevertheless, the Land Matrix is a unique source of vetted and codified information to evaluate the relationship between land deals and food systems at the global scale. The approximately 1,900 land deals of the Land Matrix database were filtered using the following criteria (see *SI Appendix* for details): 1) having its status updated to "contracted," "in startup phase," or "in production" after 2000; 2) being greater than 200 ha and intended for agricultural use; 3) entailing a transfer of user rights from smallholders and communities to foreign commercial users and involving either the sale, lease, or concession of land; and 4) having accurate coordinates of the corresponding deal locations.

This procedure resulted in a final sample of 160 deals, for which the centroid coordinates, surface area, contract date, and intended crops were obtained from the Land Matrix. The final sample comprises 197 distinct locations (a land deal can focus on several locations) and represents a total surface area of 4.06 million hectares in 39 countries. Geographically, the sample has 43 deals (0.58 Mha) in Asia, 11 deals (0.55 Mha) in Latin America, 33 deals (0.54 Mha) in eastern Europe, and 73 deals (2.40 Mha) in sub-Saharan Africa. The selected deals are either marked as "in production" (139 deals), "in startup phase" (18 deals), or "contracted" (3 deals). Note that the land cover analysis was performed on the subset of 129 deals (153 locations) with contract dates between 2005 and 2015, which correspond to the two approximate points in time when crop cover data are available. Deal sizes range between 200 and 470,000 ha, and investor intentions reported in the land matrix include "food crops" (58% of deals), "nonfood" or "unspecified" agriculture (38% of deals), "biofuels" (17% of deals), "timber plantations" (11%), and "livestock" (12%). Note that 36% of the selected deals report more than one intention. These characteristics and the data associated with all analyses below are openly available at https://doi.org/10.7274/r0-ycpf-qh53.

The actual coverage of the deals is not provided by the Land Matrix dataset and was approximated for each deal location as a disk of equivalent area and centroid (Fig. 2*A*). Validation against shapefile data for a subset of deals with known coverage is described in *SI Appendix*. Control areas B_i ($i \in [1, 3]$) were defined as encompassing the area between distances of $r \cdot i$ and $r \cdot (i+1)$ from the deal centroid, where r is the radius of the disk corresponding to the relevant deal (Fig. 2*A*). Areas of the controls that overlap with other known deals were removed. It is possible that the approximated deal areas include land that lies outside the deal's boundaries. It is similarly possible that the control areas include land from deals that are not included in our sample. While both issues raise concerns of potential sample contamination, we show, in *SI Appendix*, that they are unlikely to have a significant impact on the results.

Targeting of Prime Land. To determine whether deals target prime agricultural lands, we compared the characteristics of each deal location to the average characteristics across all cropland areas (from ref. 63) within the country containing the deal. This comparison defines a "targeting ratio" describing the extent to which the deal is located in an area exhibiting more or less of each land characteristic examined. Land characteristics examined include market access (from ref. 41), crop suitability (from ref. 38), relative crop yield for 17 major crops, average yield gaps for 17 major crops (from ref. 40), green water availability (from ref. 45), and existing irrigation infrastructure circa year 2000 (from ref. 48). Green water availability describes the location's suitability for non water-stressed rain-fed agriculture and is defined using an index varying from zero to three, adapted from ref. 45. An index of zero indicates that the pixel experiences three or more months of green water scarcity during the growing season, while an index of three indicates that the pixel experiences zero months of green water scarcity during the growing season. Irrigation infrastructure targeting is only assessed for water-limited deals, that is, in areas where the green water availability index equals zero. We compare local irrigation infrastructure in these areas to the average prevalence of irrigation infrastructure across water-limited croplands in each country. Relative crop yields are defined by normalizing crop yields circa 2000 (39) to their country averages, then constructing an area-weighted average across all crops examined. Major crops analyzed include maize, wheat, rice, soybean, barley, sorghum, millet, cotton, rapeseed, groundnut, sunflower, sugarcane, potato, cassava, oil palm, rye, and sugar beet. For each land characteristic X, we calculated the mean targeting ratio (MTR) as the ratio between the mean characteristic across deals to the (weighted) mean characteristic across the corresponding countries,

$$MTR_X = \frac{\sum_i^{deals} X_i}{\sum_j^{Countries} N_j X_j},$$

where N_j is the number of deals included for country j. The CI on the MTR is generated through nonparametric bootstrap resampling (1,000 repetitions).

Cropland Expansion and Intensification. Crop cover estimates for 2005 and 2015 were obtained from two distinct datasets. The European Space Agency 2005 Global Land Cover Product (Globcover2005) (64) has a resolution of 300 m, with four crop intensity categories indicating the percentage of each pixel covered by crops in 2005 ($<20\%$, 20 to 50%, 50 to 70%, and $>70\%$). The NASA Global Food Security-support Analysis dataset (65–69) (GFSAD30) has 30-m-resolution binary pixels indicating cultivation status in 2015 (crop vs. noncrop). Since all selected deals were completed between 2005 and 2015, the two datasets provide an estimate of crop cover before and after the land deals, albeit using distinct methodological approaches. These intrinsic methodological differences might cause systematic differences in estimated cropland that are important to consider when interpreting overall trends. However, we do not expect them to affect our results, which rely on a difference-and-difference identification strategy that explicitly controls for systematic shifts. Crop intensities in 2015 were computed by aggregating the 30-m GFSAD30 dataset to match the 300-m Globcover2005 grid. Crop coverage fractions at 300-m resolution were then computed from each group of 100 binary GFSAD30 pixels and segmented into the same categories as Globcover2005. Crop coverage in 2005 was computed by multiplying each Globcover2005 category by a coefficient corresponding to the average CCF obtained for this category for each continent, when aggregating the GFSAD30 dataset. We replicated the analysis using global (instead of regional) average crop intensities, with nearly identical estimates of fractional crop cover for each deal (see discussion in *SI Appendix*, Text and Fig. S2).

The relative change in the fraction of the deal area covered by crops (i.e., the CCF) for each group g (deal or control areas) and each land deal i was then computed as

$$rCCF_{ig} = \frac{CCF_{ig,2015}}{CCF_{ig,2005}} - 1.$$

The change in the fraction of crop cover located in heavily cultivate land (SDCF) was computed as

$$\Delta SDCF_{ig} = \frac{C^{(70)}_{ig,2015}}{CCF_{ig,2015}} - \frac{C^{(70)}_{ig,2005}}{CCF_{ig,2005}},$$

where $C^{(70)}_{ig,2015}$ indicates the area fraction of group g for deal i covered by heavily cultivated land, defined as $>70\%$ crop cover by 300-m pixel. The expected values of $rCCF_{ig}$ and $\Delta SDCF_{ig}$ for each group g, and the associated CIs, were obtained through nonparametric bootstrap (1,000 repetitions). The effect of each deal i on the extent or spatial consolidation of crop cover was evaluated as

$$\delta_i = X_{i,DEAL} - X_{i,CONTROL},$$

where $X_{i,DEAL}$ and $X_{i,CONTROL}$ designate either $rCCF_{ig}$ or $\Delta SDCF_{ig}$ for the deal ($g = DEAL$) and each of the three considered control groups ($g = CONTROL$): $B1$, $B2$, and $B3$. The expectation of δ_i across deals was finally estimated through nonparametric bootstrap (1,000 repetitions), along with the P values associated with the hypothesis $\mathcal{H}_0 : E[\delta] = 0$. Accordingly, $E[\delta]$ can be interpreted as the expected excess relative change (in percentage points) in the deal area, compared to the baseline relative change in the control area.

Of note is that individual deals are weighted equally in the analysis, meaning that estimates should be interpreted as the effect of a marginal deal (no matter its size) on the considered outcome. An alternative approach, where the contribution of each deal is weighted by its surface area, is discussed in *SI Appendix*. Outcomes can then be interpreted as the effect of a marginal unit area of acquired land (no matter into how many LSLA deals it is partitioned). Results are qualitatively similar to the unweighted analysis, but are affected by a small number of large outlier deals (*SI Appendix*, Fig. S3).

A potential shortcoming of our approach lies in its inability to account for the temporal dimension of the agrarian transition. In reality, the conclusion of land deals and the expansion and subsequent intensification of cropland occur sequentially, and possibly over a substantial period. By comparing two snapshots taken a decade apart, the analysis conflates deals situated at different stages of that process. By confounding the expansion and intensification of cropland, this may dilute both estimated effects. To investigate this artifact, we replicated the analysis independently for the subsets of deals concluded in the first (2005–2010) and second (2010–2015) halves of the study period. The expectation was that the subsamples would better target the intensification (old deals) and expansion (recent deals) effects of LSLA, respectively. However, results (*SI Appendix*, Fig. S5) are nearly identical to the full sample analysis, suggesting that the weak association between LSLAs and intensified agriculture did not emerge from unaccounted time lags.

Crop Type Transitions. We identified crops that were in the area prior to the deal using the dataset described in ref. 39, which contains crop area for 175 crops at a 5-min spatial resolution in circa the year 2000. For each deal location, we calculated the fractional harvested area of the most prevalent crops, which, together, met or exceeded 75% of the total harvested area. Intended crops were identified for each deal based on the crop intentions reported in the Land Matrix dataset, assuming equal area coverage for each intended crop. The average crop compositions of deals by continent (Fig. 3*A*) were computed as the (unweighted) mean of the crop composition of individual deals,

$$F_{ct} = \frac{1}{N_d} \sum_i F_{cit},$$

where $F_{cit} = A_{cit}/A_{it}$ is the fraction of the harvested area A_{it} of deal i occupied by crop c on period t (i.e., *ca.* 2005 with observed crop types, or *ca.* 2015 with intended crop types). N_d is the number of considered deals. For the crop transitions displayed in Fig. 3*A*, the approximately 120 individual crop types from the constructed dataset were aggregated into seven crop categories, following the Indicative Crop Classification system from the Food and Agriculture Organization (70). We computed average crop outcome C_{vt} across deals for each period by weighing crop-specific outcomes X_{civ} by the corresponding crop fraction area F_{cit},

$$C_{vt} = \frac{1}{N_d} \sum_{c,i} F_{cit} X_{civ}.$$

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Each crop-specific outcome X_{civ} represents a value associated with outcome v and crop c at deal location i and was determined as follows for the different considered outcome. The likelihood of export for each crop type and each country was determined by computing country-level ratios between export and production tonnages. Temporally averaged (2009–2013) crop production data were obtained for each relevant crop and country from the Food and Agriculture Data (FAOSTAT) platform (https://www.fao.org/faostat/en/#home) of the Food and Agriculture Organization. We obtained crop-specific nutrient contents (in mass of nutrient per mass of harvested crop) for each country for seven key macronutrients and micronutrients (folate, calcium, calories, plant-derived proteins, iron, zinc, and vitamin A) from FAOSTAT's food balance sheets. We assumed constant yields across all locations per crop and constructed a deal-level score for each nutrient by weighing crop-specific nutrient contents by the corresponding harvested area fractions, as shown in the equation. Note that, because some edible crops (e.g., maize, sugar cane, palm oil) have both food and nonfood (e.g., biofuel) applications, this overestimates the nutrients actually available to human consumption. Given the documented association between land deals and flex crops, we are likely to overestimate nutrient production after the land acquisition, hence producing a conservative estimate of the effect of land deals. Lastly, the relative change in crop diversity was computed in terms of mean number of distinct crop types per deal. For all outcomes, a nonparametric bootstrap (1,000 repetition) was run to estimate 95% CIs around C_{vt} for each region.

Similar to the land use analysis, individual deals are weighted equally in the analysis, meaning that estimates should be interpreted as the effect of a marginal deal (no matter its size) on the considered outcome. An alternative approach weighs the contribution of each deal by its surface area. Results of this alternate approach could be interpreted as the effect of a marginal surface area of acquired land and are presented in *SI Appendix*, Figs. S7 and S8, with qualitatively similar results.

Household Dietary Diversity. We obtained dietary diversity outcomes for 4,520 households from DHS that overlap spatially with the considered land deals or their respective control areas. The considered households were surveyed in one of 17 cross-sectional DHS waves administered in 11 countries in sub-Saharan Africa between 2006 and 2014 (*SI Appendix*, Table S3). Approximately half of the households were surveyed before (after) the contract year of the nearest land deal. We estimated an IDDS (55) for each child based on reported intake from 10 food groups during the previous 24 h: cereal grains, white tubers and root foods, dark leafy greens, vitamin A-rich vegetables/tubers, vitamin A-rich fruits, other fruits and vegetables, meat and fish foods, eggs, legumes/nuts/seeds, and milk and milk products. The IDDS of each child ranged between 0 and 10, depending on whether their dietary intake over the previous 24 h included at least one food item belonging to none (IDDS = 0) or to all (IDDS = 10) of these 10 groups. As a robustness check, we replicated all analyses using an alternative dietary diversity score (the minimum dietary diversity score) that is based on seven food groups (71), with nearly identical results (*SI Appendix*, Table S7). The mean IDDS across all children below 5 y old was computed for each household. As a further robustness check, we repeated the regression analyses using the minimum IDDS for each household, with comparable results (*SI Appendix*, Table S6, columns 4 and 5). DHS households were spatially joined with several geographic and agroecological variables known to potentially affect dietary diversity (e.g., refs. 72–74), including tree cover (from ref. 75), livestock density (from ref. 76), distances to the nearest road (from ref. 77) and urban center (from ref. 78), and population density (from ref. 79). Additional covariates obtained directly from DHS data include travel time to water source, age of youngest child, gender and education level of household head, access to improved sanitation or water supply, and whether the household lies in the lowermost or uppermost wealth quintiles of their community. A comprehensive list of the considered covariates is given in *SI Appendix*, Table S4, along with summary statistics of the sampled households in *SI Appendix*, Table S5. To estimate the effect of land deals on IDDS, we regressed household-level IDDS against a "postdeal" dummy variable indicating whether the household was surveyed before or after the contract date of the closest land deal. This specification was carried out on the subset of 2,671 households corresponding to two Liberian deals with surveys taken both before and after the deal contracts. (Most other deals have their associated households surveyed either before or after their implementation; see *SI Appendix*, Table S3.) Regression coefficients were estimated through ordinary least squares with standard errors clustered by land deal. To evaluate the effect of land deals on time trends of dietary diversity, we interacted the postdeal dummy variable with the year of the survey. To avoid colinearity issues between the postdeal dummy and the survey year (Liberian households were sampled in two waves: one before and one after the deals), we carried out the analysis on the full sample all 4,520 households. Regression coefficients were estimated through restricted maximum likelihood, controlling for deal-level random effects. A statistically significant regression coefficient for the interaction term indicates that the deals are associated with a change in the temporal trend of dietary diversity. Further methodological details and robustness checks are discussed in *SI Appendix*.

Data Availability. Table of land deals and characteristics has been deposited in CurateND (https://doi.org/10.7274/r0-ycpf-qh53) (80).

ACKNOWLEDGMENTS. We thank Dr. Sandra Eckert and Mokganedi Tatlhego for their help in the visual analysis. We also thank Taylor Ricketts and Brendan Fisher for their assistance with the dietary diversity dataset. We acknowledge financial support from the US NSF under Grant ICER 1824951 (M.F.M and G.P.) and the National Socio-Environmental Synthesis Center under funding received from the NSF (Grants DBI-1639145 and DBI-1052875). The dietary diversity data and analysis was made possible through funding from the US Department of Agriculture Hatch Program (Grant VT-H02303, Accession no. 1010486), and from the Biodiversity Results and Integrated Development Gains Enhanced Program of the USAID, and the Luc Hoffman Institute at WWF International under funding from the Mava Foundation.

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