Supplementary Material

Cross-Scale Vulnerability Assessment for Smallholder Farming: A Case Study in the Northeast of Brazil

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Table S1. Reviewed indices for region, farm and field scale.

| Reference               | Region                              | Concept*                                           | Data availability | Dryland Brazil | Northeast Brazil | Climate sensitive |
|-------------------------|-------------------------------------|----------------------------------------------------|-------------------|----------------|------------------|-------------------|
| Awolala & Ajibefun 2015 | Nigeria                             | V=f(Exposure, sensitivity, adaptive capacity)      | 0                 | 1              | 0                | 1                 |
| Bouroncle 2017          | Guatemala, El Salvador, Honduras, Nicaragua | V=f(Exposure, sensitivity, adaptive capacity)      | 1                 | 1              | 0                | 1                 |
| Gomez 2013              | Philippines                         | V=f(Exposure, sensitivity, adaptive capacity)      | 0                 | 0              | 0                | 1                 |
| Harvey 2014             | Madagascar                          | V=f(Exposure, sensitivity, adaptive capacity)      | 0                 | 0              | 0                | 1                 |
| Hiremath and Shiyan 2013| India                               | V=f(Exposure, sensitivity, adaptive capacity)      | 0                 | 1              | 0                | 1                 |
| Legese et al 2016       | Ethiopia                            | V=f(Exposure, sensitivity, adaptive capacity)      | 0                 | 1              | 0                | 1                 |
| Lindoso et al 2011, 2012, 2014 | Ceará, Brazil                  | V=f(Exposure, sensitivity, adaptive capacity)      | 1                 | 1              | 1                | 1                 |
| Pandey and Jha 2012     | Lower Himalaya, India               | V=f(Exposure, sensitivity, adaptive capacity)      | 0                 | 0              | 0                | 1                 |
| Reference             | Region                                    | Concept*                                                                 | Data availability | Dryland | Northeast Brazil | Climate sensitive |
|----------------------|-------------------------------------------|--------------------------------------------------------------------------|-------------------|----------|------------------|-------------------|
| Pandey et al 2015    | Himalaya Mountains, India                 | $V = f(\text{Exposure, sensitivity, adaptive capacity})$                  | 0                 | 0        | 0                | 1                 |
| Panthi 2015          | Nepal                                     | $V = f(\text{Exposure, sensitivity, adaptive capacity})$                  | 0                 | 0        | 0                | 1                 |
| Rosendo 2014         | Paraíba, Brazil                           | $V = f(\text{Exposure, sensitivity, adaptive capacity})$                  | 1                 | 1        | 1                | 1                 |
| Sabino 2013          | Ceará, Brazil                             | $V = f(\text{social, environmental, economic, institutional aspects})$    | 1                 | 1        | 1                | 0                 |
| Sietz et al 2006     | Ceará, Piauí, Pernambuco, Brazil          | vulnerability dynamics = $f(\text{trends of resource quality and yield oriented labour})$ | 1                 | 1        | 1                | 0                 |
| Tesso et al 2012     | Ethiopia                                  | $V = f(\text{Exposure, sensitivity, adaptive capacity})$                  | 0                 | 0        | 0                | 1                 |

**Farm Scale**

| Reference             | Region                                    | Concept*                                                                 | Data availability | Dryland | Northeast Brazil | Climate sensitive |
|----------------------|-------------------------------------------|--------------------------------------------------------------------------|-------------------|----------|------------------|-------------------|
| Bishop & Fuller 2015 | Nicaragua                                 | resilience = $f(\text{livelihood viability, innovation potential, contingency resources, environment, social capability})$ | 1                 | 0        | 0                | 0                 |
| Blesh & Wittman 2015 | Mato Grosso, Brazil                       | resilience = $f(\text{control over production and consumption})$        | 0                 | 0        | 0                | 0                 |
| Finan and Nelson 2001| Ceará, Brazil                             | $V = f(\text{subsistence production, income from agriculture and livestock})$ | 0                 | 1        | 1                | 0                 |
| Luers et al 2003     | Mexico                                    | $V = f(\text{Exposure, sensitivity, adaptive capacity})$                  | 0                 | 1        | 0                | 1                 |
| Oxfam 2013           | Nepal                                     | resilience = $f(\text{livelihood viability, innovation potential, contingency resources, environment, social capability})$ | 1                 | 1        | 0                | 0                 |
| Oxfam 2013           | Ethiopia                                  | resilience = $f(\text{livelihood viability, innovation potential, contingency resources, environment, social capability})$ | 1                 | 1        | 0                | 0                 |
| Petersen et al 2017  | northeast Brazil                          | sustainability                                                             | 1                 | 1        | 1                | 0                 |

**Field Scale**

| Reference             | Region                                    | Concept*                                                                 | Data availability | Dryland | Northeast Brazil | Climate sensitive |
|----------------------|-------------------------------------------|--------------------------------------------------------------------------|-------------------|----------|------------------|-------------------|
| Amara et al 2014     | Sierra Leone                              | soil fertility (soil degradation rate, potential vulnerability)          | 1                 | 0        | 0                | 0                 |
| Akpan-Idiok & Ofem 2014| Nigeria                                  | soil quality (soil degradation rate, potential vulnerability)            | 0                 | 0        | 0                | 0                 |
| Cherubin et al 2016  | Brazil, Goiás, São Paulo                 | sustainability = $f(\text{soil quality impact of land use change})$     | 1                 | 0        | 0                | 0                 |
| Reference             | Region               | Concept                                                                 | Data availability | Dryland Brazil | Northeast Brazil | Climate sensitive |
|-----------------------|----------------------|-------------------------------------------------------------------------|-------------------|----------------|------------------|------------------|
| Fialho 2013           | Ceará, Brazil        | soil quality = f(water retention+nutrients supply + promotion of biological activity), soil resistance & resilience | 0                 | 1              | 1                | 0                |
| Gelaw et al 2015      | Ethiopia             | Soil quality = ability to 1) accommodate water entry, 2) facilitate water movement and availability, 3) resist degradation, 4) supply nutrients for plant growth | 0                 | 1              | 0                | 0                |
| Silva et al 2011      | Ceará, Brazil        | physical soil quality                                                   | 0                 | 1              | 1                | 0                |
| Stefanoski et al 2016 | Piauí, Brazil        | soil quality = f(physical, chemical, biological indicators)             | 0                 | 0              | 1                | 0                |
| Ukabiala et al 2016   | Nigeria              | sustainability = f(soil degradation rate, potential vulnerability)      | 0                 | 0              | 0                | 0                |
| Uquetan et al 2017    | Nigeria              | landuse change effect on soil quality (soil degradation rate, potential vulnerability) | 0                 | 0              | 0                | 0                |
| Vendruscolo and Perez Marin (2017) | Brazil, Northeast | soil quality = f(degraded/preserved soils)                             | 1                 | 1              | 1                | 0                |

* V: Vulnerability
Table S2. Results of municipality index 1.

| Municipality       | inco | engag | water | rainf | p div | land | read | assoc | techn | electr | Al  | S   | AC   | E    | M1  |
|--------------------|------|-------|-------|-------|-------|------|------|-------|-------|-------|-----|-----|------|------|-----|
| Alagoa Nova        | 87.2 | 19.0  | 79.8  | 96.7  | 56.8  | 85.8 | 56.8 | 64.9  | 1.5   | 92.9  | 0.69| 0.64| 0.56| 0.11| 0.40|
| Algodão de Jandaíra| 35.7 | 18.8  | 65.5  | 100.0 | 58.6  | 80.0 | 33.6 | 70.7  | 12.1  | 85.7  | 0.28| 0.41| 0.48| 1.00| 0.65|
| Arara              | 32.1 | 27.5  | 75.9  | 99.7  | 77.5  | 81.0 | 43.6 | 68.9  | 1.3   | 82.9  | 0.66| 0.54| 0.54| 0.17| 0.39|
| Areia              | 63.6 | 20.2  | 88.1  | 98.4  | 38.9  | 61.6 | 50.7 | 60.1  | 8.6   | 86.3  | 0.72| 0.68| 0.32| 0.03| 0.47|
| Areial             | 33.1 | 23.2  | 63.6  | 100.0 | 63.9  | 57.1 | 58.6 | 77.7  | 51.3  | 84.7  | 0.41| 0.41| 0.63| 0.71| 0.50|
| Borborema          | 98.0 | 13.7  | 84.7  | 93.9  | 69.1  | 76.0 | 54.0 | 65.8  | 9.5   | 76.4  | 0.74| 0.64| 0.50| 0.00| 0.38|
| Campina Grande     | 57.1 | 1.3   | 78.5  | 97.7  | 48.3  | 55.8 | 62.6 | 35.2  | 7.3   | 86.9  | 0.38| 0.47| 0.27| 0.78| 0.66|
| Casserengue        | 39.2 | 28.7  | 74.4  | 100.0 | 68.1  | 73.4 | 40.4 | 52.1  | 9.8   | 82.1  | 0.38| 0.56| 0.41| 0.78| 0.64|
| Esperança          | 30.4 | 16.6  | 69.7  | 98.6  | 71.5  | 64.6 | 50.6 | 74.0  | 4.7   | 84.9  | 0.48| 0.40| 0.50| 0.56| 0.48|
| Lagoa Seca         | 87.3 | 16.1  | 64.0  | 86.8  | 77.7  | 89.9 | 74.3 | 43.0  | 4.0   | 93.8  | 0.51| 0.30| 0.67| 0.50| 0.38|
| Massaranduba       | 29.2 | 30.0  | 79.6  | 99.3  | 72.1  | 58.7 | 50.5 | 58.3  | 4.2   | 74.9  | 0.55| 0.57| 0.36| 0.41| 0.54|
| Matinhas           | 91.7 | 50.7  | 79.9  | 98.9  | 71.7  | 66.3 | 64.3 | 66.5  | 0.8   | 89.1  | 0.63| 0.86| 0.54| 0.24| 0.52|
| Montadas           | 29.7 | 28.5  | 65.5  | 99.2  | 67.3  | 80.9 | 67.3 | 66.7  | 9.0   | 86.8  | 0.40| 0.43| 0.62| 0.74| 0.52|
| Pilões             | 94.5 | 27.3  | 90.8  | 99.3  | 40.6  | 62.0 | 44.7 | 59.2  | 4.2   | 84.5  | 0.73| 0.86| 0.28| 0.02| 0.53|
| Puxinanã           | 40.8 | 20.6  | 67.0  | 97.7  | 62.1  | 90.5 | 79.8 | 39.6  | 6.7   | 97.6  | 0.38| 0.41| 0.64| 0.78| 0.52|
| Queimadas          | 41.6 | 21.5  | 77.0  | 97.9  | 51.6  | 63.4 | 61.0 | 41.3  | 2.8   | 92.3  | 0.38| 0.51| 0.36| 0.78| 0.64|
| Remígio            | 64.1 | 14.2  | 74.1  | 99.6  | 77.6  | 65.2 | 43.6 | 65.8  | 8.4   | 80.8  | 0.51| 0.55| 0.47| 0.49| 0.52|
| S. Sebastião L.R.  | 31.5 | 29.7  | 72.4  | 95.8  | 61.3  | 82.7 | 60.7 | 69.8  | 8.3   | 94.1  | 0.56| 0.44| 0.63| 0.38| 0.40|
| Serra Redonda      | 16.7 | 31.2  | 79.1  | 99.7  | 72.4  | 79.2 | 51.8 | 61.9  | 0.3   | 79.5  | 0.52| 0.54| 0.49| 0.47| 0.51|
| Serraria           | 65.9 | 28.6  | 76.1  | 99.0  | 71.4  | 64.7 | 51.0 | 66.8  | 5.5   | 77.1  | 0.74| 0.63| 0.44| 0.00| 0.40|
| Solânea            | 22.7 | 16.6  | 76.1  | 99.4  | 73.8  | 78.2 | 37.0 | 72.2  | 6.8   | 74.2  | 0.59| 0.45| 0.47| 0.32| 0.43|

S. Sebastião L.R.: São Sebastião de Lagoa de Roça; M1: municipality index 1; Subindices S: Sensitivity; AC: Adaptive capacity; E: Exposure; Indicators inco: dependence of farm income on crop and animal production; engag: Municipal population engaged in agriculture; water: Farms without access to water storage; rainf: Farms with rainfed farming; p div: Product diversification; land: Farms in which the producer is the landowner; read: Farms whose heads can read and write; assoc: Farms whose heads are engaged in associations or unions; techn: Farms receiving technical assistance; electr: Farms with access to electric energy supply; Al: Aridity Index. All indicators refer to smallholder farming/agriculture.
Table S3. Results of municipality index 2.

| Municipality                      | 2002 - 2006 |                                       | 2012 - 2016 |                                         | Bex (%) |
|-----------------------------------|-------------|---------------------------------------|-------------|------------------------------------------|---------|
|                                   | Trend(ly)   | Trend(rq) | R²(ly) | R²(rq) | State | Trend(ly) | Trend(rq) | R²(ly) | R²(rq) | State |         |
| Alagoa Nova                       | 1827.7      | 0.0007    | 0.87   | 0.00   | III   | -2140.6   | 0.0423    | 0.77   | 0.24   | II    | 8.7     |
| Algodão de Jandaíra               | 564.1       | 0.0077    | 0.41   | 0.04   | III   | -460.5    | -0.0336   | 0.94   | 0.53   | I     | 5.3     |
| Arara                            | 1626.4      | 0.1270    | 0.91   | 0.75   | III   | 435.8     | -0.0576   | 0.30   | 0.14   | IV    | 10.3    |
| Areia                            | 1962.6      | 0.0917    | 0.49   | 0.95   | III   | 1195.9    | 0.0286    | 0.62   | 0.49   | III   | 13.4    |
| Areial                           | 290.1       | 0.0903    | 0.49   | 0.45   | III   | -612.2    | -0.0673   | 0.97   | 0.16   | I     | 12.4    |
| Borborema                         | 638.1       | 0.0174    | 0.86   | 0.65   | III   | 159.1     | -0.0007   | 0.18   | 0.00   | IV    | 8.7     |
| Campina Grande                   | -99.1       | 0.0105    | 0.04   | 0.22   | II    | -460.4    | -0.0095   | 0.05   | 0.01   | I     | 29.0    |
| Casserengue                       | 1980.4      | 0.1068    | 0.74   | 0.89   | III   | 583.0     | -0.0749   | 0.29   | 0.30   | IV    | 4.6     |
| Esperança                         | 2310.4      | 0.1526    | 0.82   | 0.80   | III   | 82.0      | -0.0409   | 0.02   | 0.23   | IV    | 12.0    |
| Lagoa Seca                        | 859.7       | 0.0249    | 0.85   | 0.24   | III   | -66.1     | -0.0109   | 0.01   | 0.01   | I     | 12.5    |
| Massaranduba                     | -3590.8     | -0.0588   | 0.89   | 0.44   | I     | -2009.5   | -0.0474   | 0.86   | 0.45   | I     | 7.8     |
| Matinhos                         | 1087.3      | -0.0049   | 0.95   | 0.01   | IV    | -593.9    | -0.0493   | 0.47   | 0.07   | I     | 5.0     |
| Montadas                         | -78.8       | 0.1107    | 0.03   | 0.91   | II    | -151.8    | 0.0470    | 0.25   | 0.05   | II    | 10.9    |
| Pilões                           | -74.9       | -0.0314   | 0.01   | 0.28   | I     | -0.3      | 0.0862    | 0.00   | 0.65   | II    | 10.3    |
| Puxinanã                         | 1283.0      | 0.1494    | 0.59   | 0.75   | III   | -2154.3   | 0.0207    | 0.86   | 0.02   | II    | 9.9     |
| Queimadas                         | 477.3       | 0.0509    | 0.36   | 0.40   | III   | -1508.2   | -0.0248   | 0.96   | 0.19   | I     | 10.6    |
| Remígio                          | 1895.4      | 0.1489    | 0.86   | 0.95   | III   | 178.7     | 0.0538    | 0.13   | 0.18   | III   | 13.3    |
| São Sebastião de Lagoa de Roça    | -1201.2     | 0.0297    | 0.80   | 0.38   | II    | -914.2    | -0.0295   | 0.93   | 0.12   | I     | 10.0    |
| Serra Redonda                    | -24.2       | 0.0474    | 0.04   | 0.50   | II    | 27.4      | 0.0308    | 0.01   | 0.27   | III   | 9.3     |
| Serraria                         | -254.1      | 0.0095    | 0.27   | 0.13   | II    | -1778.6   | -0.0041   | 0.73   | 0.27   | I     | 6.6     |
| Solânea                          | 572.4       | 0.0365    | 0.18   | 0.94   | III   | 1181.8    | -0.0397   | 0.57   | 0.32   | IV    | 11.0    |

Bex: existential budget (% of municipal population earning at least one minimum wage); ly: yield oriented labor; R²: coefficient of determination; rq: resource quality.
Table S4. Results of farm index 1.

| Dimension | Characteristic | Threshold: HH scores positively if… | Score | Farm 1, Areial | Farm 2, Remigio |
|-----------|----------------|--------------------------------------|-------|---------------|----------------|
| Livelihood viability (30 %) | Land ownership | HH owns at least 4 ha. | 0.02 | 8.5 ha | 10.5 ha (+2.5 in collective area) |
| | HH wealth status | HH owns ≥ 3 large assets or ≥ 6 small assets* | 0.02 | Big assets: motorcycle, fridge, F1: pigs. F2: horse | No problems with food supply |
| | HH food security | HH reports having enough food for all HH members. | 0.02 | | |
| | Livelihood diversification | HH engages in ≥ 2 livelihood activities with ≥ 50% dependency on activities assumed to be significantly drought tolerant. | 0.02 | Crops, drought tolerant fodder plants, fodder and water stocks for livestock, pension | F1: man is mason. F2: woman repairs clothes. |
| | Crop diversification | HH cultivated at least 3 crop types, including at least one drought-resistant crop. | 0.02 | Beans, maize, manioc (drought resistant) | Beans, maize, sweet potato, potato, fodder cactus (drought resistant) |
| | Crop production | HH sold crops during the past 12 months (i.e. the HH produced enough to be able to sell the surplus). | 0.02 | Sold beans, maize | |
| | Livestock diversification | HH is dependent on at least 3 types of animals, including some cattle. | 0.02 | Cattle, pigs, chicken | Cattle, traction horse, chicken, guineafowls |
| | Livestock herd size | HH owns at least 5 cattle or 40 pigs, sheep or goats. | 0.02 | 7 heads of cattle | 15 heads of cattle |
| | Ownership of means of transport | It owns at least 1 traction animal (horse, ox or donkey) or motorcycle | 0.02 | Motorcycle | F1: traction ox, F2 traction horse |
| | Livestock lost to drought or diseases | No large livestock (bull, cow, horse donkey) AND < 3 medium livestock (goat, sheep, pig) AND < 6 poultry birds | 0.02 | Silo helps to supply good feed to the cattle even in drought periods, production cistern supplies water, reported no problems with diseases | Cattle are vaccinated. |
| | Livestock vaccination | At least two-thirds of the livestock types (mammals) owned by the HH are vaccinated | 0.02 | | F1: pigs treated against parasites |
| | Drought preparedness practice | HH did at least two of the “good” practices during the last years. ** | 0.02 | Silo, cisterns, reservoirs; buys feed for chicken and pigs; cultivates maize, fodder cactus and different pastures | Silo, cisterns, reservoirs; can use pasture of children for grazing; cultivates maize, fodder cactus, agave and different pastures |
| | Access to markets | HH members take less than 90 minutes to travel to the nearest town. | 0.02 | Access to local market of municipality, agroecological markets of Borborema territory and bigger market of Arara | |
| Dimension          | Characteristic                          | Threshold: HH scores positively if... | Score | Farm 1, Areial                                                                 | Farm 2, Remigio                                                                 |
|--------------------|-----------------------------------------|--------------------------------------|-------|--------------------------------------------------------------------------------|--------------------------------------------------------------------------------|
| **Innovation potential (20 %)** |  |  |  |  |  |
| Attitudes towards new livelihood practices | Interest in new livelihood practices. | **0.04** | Interested in learning new practices; experimental farmer, participate in farmers exchanges and research projects |  |
| Adoption of improved production techniques | HH applies at least 4 improved agricultural production techniques. *** | **0.04** | Manure compost, living fences, crop rotation, storing grain for food, silo and seed for future planting, kitchen garden | Manure, biofertilizer, nim tree as pesticide, living fences, crop rotation, storing grain for food, silo, seed for future planting, kitchen garden, agroforestry system |
| Access to credit | HH took out loan in last years Or could borrow in the event it was needed from a money lender, non-local family members, savings group, or bank/credit institution. | **0.04** | Participates in FRS for manure, tarpaulin, fences ecologic stove, 2013 credit from Pronaf, children send some money | 2013 credit from Pronaf to build a new reservoir and plant 1 ha of brachiara grass |
| Access to state innovative support | HH accessed state extension support in new techniques in the last years and finds the support at least moderately helpful | **0.04** | 2012 P1+2 to build a production cistern | 2009 P1+2 to build production cistern, 2012 P1+2 to build the seed bank |
| Ability to influence others | Respondent shares knowledge of production techniques with other HH members or with others in the community, at least sometimes they applied what they had told them. | **0.04** | After observing that the silo was a useful feed supply for droughts, some community members wanted to learn to prepare silo, now they prepare silo together every year. |  |
| **Access to contingency resources and support (20 %)** |  |  |  |  |  |
| Group participation | Respondent reports being an active participant in at least 2 groups with medium involvement in decision making in at least one. | **0.03** | Participation in STR, since 2001 in the direction, 2001 Association of Sitio Furnas | Since 1998 involved with MST, 1999 Association Oziel Pereira, 2002 participation in STR |
| Access to government emergency support | Applied government emergency support measures. | **0.03** | Seguro safra (harvest insurance) | 1 registered community cistern to get water from the military |
| Savings | HH has enough savings to survive for at least 30 days in a drought or support costs of an immediate need (e.g. hospital). | **0.03** | Pension is independent from drought, cattle serves as saving for an immediate need. |  |
| Grain storage | HH has stored grain for future use as food in the past 12 months. | **0.03** | beans |  |
| Access to remittances or state support | HH has some income from remittances or payments from government. | **0.03** | Pension, F1: children send some money |  |
| Dimension | Characteristic | Threshold: HH scores positively if... | Score | Farm 1, Areial | Farm 2, Remigio |
|-----------|----------------|-------------------------------------|-------|----------------|----------------|
| Ownership of fungible livestock | HH owns at least 20 poultry birds. | 0.03 | 80 chicken | 30 chicken+ 4 guineafowls |
| Extent of soil erosion | It does not report experiencing severe erosion. | 0.03 | No severe erosion observed |
| Access to irrigation | At least some of the land cultivated by the HH is irrigated OR only a small portion of its crops was lost during the last years of drought. | 0.00 | No irrigation, yield decreased considerably in drought years. |
| Access to water for livestock/consumption | It did not report experiencing serious difficulties in accessing water for domestic or livestock use during the last years. | 0.03 | Cisterns and reservoirs allow to store water for livestock and consumption |
| Access to grazing land | HH experienced no/only small problems in accessing suitable grazing lands during the last dry season. | 0.03 | enough grazing land increased own grazing land and can use grazing land of children |
| Tree planting | HH has planted at least 10 trees in the last 3 years. | 0.03 | Planted living fences, fruit and other trees F2: Agroforestry system |
| Access to drought warning information | HH receives information about the drought situation from community leaders, committee, government or radio. | 0.04 | Access to information by STR, Association, radio, TV |
| Drought preparedness plan | There is a drought preparedness plan for the region made by the local government or other institutions. | 0.00 | There are some programs but rather to remediate the direct damages than to make farmers less vulnerable to droughts. ASA, AS-PTA, STR, Borborema Polo |
| Institutions supporting adaptation | There are programs from local leaders or community institutions supporting adaptation to drought. | 0.04 | |
| Solidarity in the community | HH provided support to others and/or received support from others in the community at least 1 time during the past 12 months. | 0.04 | Help on relatives’ farm when they get sick Always care about their grandchildren, share products with neighbors and family |

* Large assets: bulls, pigs, horses, fridge, satellite dish, oven, motorcycle or other vehicle; small assets: radio, mobile phone, TV, mattress, horse/ox cart, solar panel, bicycle. ** “Good” livestock practices: Migrated with animals; destocked livestock; split herds; purchased feed or water to store; gave some animals to others to care for. *** Improved agricultural production techniques: use of organic fertilizer or insecticide, living fences, crop rotation, storing grain for food and feed, seed for planting. ASA: Partnership for the Brazilian Semi-Arid Region (Articulação Semiárido Brasileiro); AS-PTA: Family Agriculture and Agroecology (Agricultura Familiar e Agroecologia); F1, F2: farm 1, farm 2; FR5: Rotating Solidarity Fund (Fundo Rotativo Solidário); HH: household; MST: Landless Workers’ Movement (Movimento dos trabalhadores rurais Sem Terra); P1+2: Program one land and two waters (Programa Uma Terra e Duas Águas), for the construction of production cisterns, seed banks and other infrastructure to store water for plants and animals, for food, feed and seed sovereignty; Pronaf: National Program of Empowerment of Family Farming (Programa Nacional de Fortalecimento da Agricultura Familiar); STR: union of rural workers (Sindicato dos Trabalhadores Rurais).
Table S5. Results of farm index 2, farm 1 (adapted from ASA/INSA research project, unpublished material).

| Indicator                        | before 2000 | Innovations during the period | Explanation                                                                                                                                 |
|----------------------------------|-------------|--------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|
| Seed autonomy                    | 3 4         | Seed bank                      | Through farmers exchanges increased genetic diversity of plant varieties adapted to the local conditions                                      |
| Water autonomy                   | 2 4         | Construction of more cisterns and reservoirs | They had already some water infrastructure and the access to public policies allowed to increase the water storage capacity (P1+2) |
| Feed autonomy                    | 2 4         | Silo, afforestation, fodder cactus | Learnt practices to store feed and prepare silo. Stronger integration of crops and livestock, harvest residues to feed the cattle and pigs |
| Food security                    | 3 4         | More food stocks                | They produce a considerable part of their own food, storage of beans, manioc flour                                                        |
| Soil Fertility                   | 2 3         | Manure compost system, living fences | Low natural soil fertility (sandy soils), living fences and a manure compost system help to increase soil fertility                          |
| Production diversity             | 2 4         | Higher production diversity     | They increased the diversity of crops and integrated them with the practices of animal husbandry                                            |
| Market diversity                 | 2 3         | Local market with regular customers. | They produce cheese and sell it on the local market to regular customers                                                                       |
| Income diversity                 | 3 4         | Pension, family allowance (Bolsa Familia) | Production is more for self-consumption than for monetary income, man works as mason, pension, family allowance                                      |
| Gender equity                    | 3 3         | Partial division of work and decision making, participation in women marches | Man helps with some domestic work but still the woman does most of cooking and cleaning; in decision making, the man seems to have a stronger decision power; since 2012 the woman participates in the women marches |
| Social participation             | 2 4         | STR, Borborema Polo, AS-PTA     | Man participates in direction of STR, they participate in activities of the STR, network of organic farmers of Borborema, experimental farmer of AS-PTA |
| Access to public policies        | 2 4         | P1+2, Pronaf, Seguro Safra (harvest insurance) | Since Carlinhos participates in the direction of STR the family accessed a greater number of public policies                                      |
| Mean 2.36                        |             |                                |                                                                                                                                          |
| F2 0.47                          |             |                                |                                                                                                                                          |

AS-PTA: Family Agriculture and Agroecology (Agricultura Familiar e Agroecologia); FRS: Rotating Solidarity Fund (Fundo Rotativo Solidário); INCRA: National Institute of Colonization and Land Reform (Instituto Nacional de Colonização e Reforma Agrária); MST: Landless Workers’ Movement (Movimento dos trabalhadores rurais Sem Terra); P1+2: Program one land and two waters (Programa Uma Terra e Duas Águas); P1MC: Program 1 Million Cisterns (Programa Um Milhão de Cisternas); Pronaf: National Program of Empowerment of Family Farming (Programa Nacional de Fortalecimento da Agricultura Familiar); STR: union of rural workers (Sindicato dos Trabalhadores Rurais).
Table S6. Results of farm index 2, farm 2 (adapted from ASA/INSA research project, unpublished material).

| Indicator               | before 2000 | 2014 | Innovations during the period | Explanation                                                                                                                                 |
|-------------------------|--------------|------|-------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------|
| Autonomy                |              |      |                               |                                                                                                                                             |
| Seed autonomy           | 3            | 5    | Seed bank, exchange with seed network, seed experiments | They always stored their seeds, with communitarian seed bank quantity and diversity of seeds increased; seed change at farmers’ exchanges and workshops |
| Water autonomy          | 1            | 4    | Construction of reservoirs and cisterns | When they occupied the land, there was no water infrastructure; they built 3 reservoirs, 2 cisterns for drinking water (16 000 l each), 1 production cistern (52 000 l) |
| Feed autonomy           | 2            | 4    | Fodder cactus, agave, fodder trees, fodder melon, silo | Fodder cactus and agave grow with very few water, the fodder melon grows anywhere on the fields; silo supplies high quality feed for dry periods |
| Food security           | 2            | 4    | Increased crop area, diversity of plants and poultry birds | Increased crop area and food diversity, especially in the agroforestry system; production cistern improves water supply for poultry birds and some plants around the house |
| Soil Fertility          | 1            | 3    | Afforestation, agroforestry system, biofertilizer, manure, living fences | When they arrived the land was bare soil; started afforestation; planted agroforestry system and living fences around the fields; applied manure and biofertilizer |
| Responsivity            |              |      |                               |                                                                                                                                             |
| Production diversity    | 2            | 5    | Diversified food and feed production | The family increased plant and animal diversity: fruits, vegetables and medicinal plants in the Agrovila, agave, fodder cactus |
| Market diversity        | 3            | 4    | Agroecological market          | The family started to sell fruits, vegetables and seeds at agroecological market                                                                 |
| Income diversity        | 2            | 4    | Different markets, pension, clothing repair | Income from the different markets, family allowance (Bolsa Familia), pension and clothing repair                                                                 |
| Gender equity           | 2            | 3    | Woman participates in FRS, in women assemblies and marches, farmer exchanges | Woman became more integrated in social movement; participates in FRS for wire mesh and for an ecologic stove; participates in women assemblies and marches and in the farmers’ exchanges |
| Social participation    | 2            | 5    | MST, STR, Association, seed bank, Borborema Polo, farmers’ exchanges, AS-PTA | Participation in MST, Assentamento (fiscal of the association, vice president of the co-operative, seed commission of Borborema Polo, STR, education dynamics of AS-PTA |
| Access to public policies| 1            | 5    | Land Reform, INCRA, family allowance (Bolsa Familia), Pronaf, P1MC, P1+2 | Since 2000 the family accessed various public policies: access to land, build their house, cisterns and reservoirs, a house for the seed bank |
| Mean                    | 1.91         | 4.18 |                               |                                                                                                                                             |
| F2                      | 0.38         | 0.84 |                               |                                                                                                                                             |

Abbreviations see Table S5.
Analyzed and calculated soil characteristics.

| Sample | pH  | OC  | P   | Al³⁺ | H⁺Al³⁺ | Ca²⁺ | Mg²⁺ | Na⁺ | K⁺ | BD   | Sand  | Silt   | Clay | Tex  | SB  | T   | m   | ESP | SSI |
|--------|-----|-----|-----|------|--------|------|------|-----|----|------|-------|--------|------|------|-----|-----|-----|-----|-----|
| Farm 1 | 1   | 7.7 | 7.2 | 5.1  | 0.0    | 1.8  | 1.5  | 0.5 | 0.0| 0.0 | 1.6   | 899    | 68    | 34   | s   | 2.0 | 3.8 | 0.0 | 0.0 | 12.2|
|        | 2   | 8.0 | 5.9 | 21.0 | 0.0    | 1.7  | 1.6  | 0.4 | 0.0| 0.0 | 1.6   | 893    | 77    | 31   | s   | 2.0 | 3.7 | 0.0 | 0.0 | 9.5 |
|        | 3   | 6.9 | 5.2 | 2.1  | 0.1    | 2.3  | 0.5  | 0.2 | 0.1| 0.0 | 1.6   | 893    | 67    | 40   | s   | 0.8 | 3.1 | 11.1| 3.23| 8.3 |
|        | 4   | 5.9 | 21.8| 3.5  | 0.1    | 4.3  | 1.4  | 0.6 | 0.0| 0.1 | 1.4   | 724    | 158   | 118  | sl  | 2.1 | 6.4 | 4.6 | 0.0 | 13.6|
|        | 5   | 7.3 | 7.0 | 23.0 | 0.0    | 1.7  | 1.5  | 0.4 | 0.0| 0.2 | 1.6   | 893    | 81    | 27   | s   | 2.1 | 3.8 | 0.0 | 0.0 | 11.2|
|        | 6   | 7.2 | 8.7 | 20.2 | 0.0    | 1.2  | 1.5  | 0.5 | 0.0| 0.2 | 1.6   | 890    | 79    | 31   | s   | 2.2 | 3.4 | 0.0 | 0.0 | 13.6|
|        | 7   | 6.8 | 5.4 | 8.6  | 0.0    | 1.3  | 1.0  | 0.3 | 0.0| 0.2 | 1.7   | 880    | 90    | 30   | s   | 1.5 | 2.8 | 0.0 | 0.0 | 7.7 |
|        | 8   | 5.7 | 9.8 | 33.2 | 0.1    | 2.8  | 0.9  | 0.2 | 0.0| 0.1 | 1.6   | 866.0  | 80.0  | 54.0 | ls  | 1.2 | 4.0 | 7.7 | 0.0 | 12.7|
| Farm 2 | 1   | 7.5 | 16.6| 149.1| 0.0    | 1.8  | 3.9  | 0.4 | 0.0| 0.9 | 1.5   | 859    | 90    | 51   | ls  | 5.2 | 7.0 | 0.0 | 0.0 | 20.2|
|        | 2   | 6.5 | 12.9| 14.6 | 0.1    | 2.0  | 1.8  | 0.4 | 0.0| 0.5 | 1.5   | 857    | 65    | 78   | ls  | 2.7 | 4.7 | 3.6 | 0.0 | 15.5|
|        | 3   | 6.1 | 12.3| 7.6  | 0.1    | 2.6  | 1.3  | 0.5 | 0.0| 0.5 | 1.5   | 830    | 85    | 85   | ls  | 2.3 | 4.9 | 4.2 | 0.0 | 12.4|
|        | 4   | 6.1 | 13.5| 3.7  | 0.1    | 2.8  | 1.2  | 0.4 | 0.0| 0.4 | 1.4   | 834    | 89    | 77   | ls  | 2.0 | 4.8 | 4.8 | 0.0 | 14.1|
|        | 5   | 6.1 | 14.1| 6.8  | 0.2    | 2.6  | 1.6  | 0.4 | 0.0| 0.5 | 1.4   | 842    | 85    | 73   | ls  | 2.5 | 5.1 | 7.4 | 0.0 | 15.4|
|        | 6   | 6.6 | 14.4| 13.0 | 0.0    | 2.6  | 2.1  | 0.5 | 0.0| 0.9 | 1.5   | 845    | 104   | 52   | ls  | 3.5 | 6.1 | 0.0 | 0.0 | 15.9|
|        | 7   | 6.2 | 14.2| 9.2  | 0.1    | 2.8  | 1.9  | 0.5 | 0.0| 0.5 | 1.5   | 842    | 97    | 61   | ls  | 2.9 | 5.7 | 3.3 | 0.0 | 15.5|
|        | 8   | 5.8 | 13.4| 3.8  | 0.1    | 3.0  | 1.5  | 0.4 | 0.0| 0.5 | 1.4   | 847    | 77    | 77   | ls  | 2.4 | 5.4 | 4.0 | 0.0 | 15.0|
|        | 9   | 5.4 | 11.9| 3.0  | 0.2    | 3.1  | 0.7  | 0.2 | 0.0| 0.2 | 1.4   | 863    | 68    | 68   | ls  | 1.1 | 4.2 | 15.4| 0.0 | 15.0|
|        | 10  | 5.7 | 11.4| 2.5  | 0.1    | 3.6  | 1.1  | 0.3 | 0.0| 0.3 | 1.4   | 865    | 79    | 56   | ls  | 1.7 | 5.3 | 5.6 | 0.0 | 14.5|
|        | 11  | 6.0 | 18.5| 6.6  | 0.1    | 4.1  | 1.3  | 1.1 | 0.0| 0.9 | 1.4   | 754    | 74    | 172  | sl  | 3.3 | 7.4 | 2.9 | 0.0 | 13.0|
|        | 12  | 5.4 | 11.9| 2.3  | 0.2    | 4.5  | 0.9  | 0.3 | 0.0| 0.4 | 1.5   | 850    | 75    | 75   | ls  | 1.6 | 6.1 | 11.1| 0.0 | 13.7|
|        | 13  | 6.2 | 13.2| 12.4 | 0.1    | 3.6  | 1.6  | 0.5 | 0.0| 0.5 | 1.4   | 850    | 81    | 69   | ls  | 2.6 | 6.2 | 3.7 | 0.0 | 15.1|
|        | 14  | 6.0 | 12.4| 5.3  | 0.1    | 4.3  | 1.2  | 0.4 | 0.0| 0.5 | 1.4   | 837    | 93    | 70   | ls  | 2.1 | 6.4 | 4.6 | 0.0 | 13.1|
|        | 15  | 5.4 | 18.4| 4.0  | 0.1    | 4.5  | 1.5  | 0.5 | 0.0| 0.7 | 1.4   | 814    | 106   | 80   | ls  | 2.7 | 7.2 | 3.6 | 0.0 | 17.0|
|        | 16  | 5.7 | 19.3| 21.4 | 0.1    | 4.3  | 1.5  | 0.5 | 0.0| 0.5 | 1.4   | 854    | 56    | 90   | ls  | 2.6 | 6.9 | 3.7 | 1.45| 22.8|

Analyzed soil characteristics pH: potential of hydrogen in solution of H2O 1:2.5; OC: soil organic carbon; P: phosphorus; Al³⁺: aluminum (III); H⁺Al³⁺: potential acidity; Ca²⁺: calcium; Mg²⁺: magnesium; Na⁺: sodium; K⁺: potassium; BD: bulk density; Tex: soil texture due to sand, silt and clay content with s: sand, ls: loamy sand, sl: sandy loam; calculated soil characteristics SB: sum of bases; T: potential cation exchange capacity; m: saturation of exchangeable Al³⁺; ESP: exchangeable sodium percentage; SSI: structural stability index.
| Sample | OC  | P   | K⁺  | SSI  | BD  | pH  | S1  |
|--------|-----|-----|-----|------|-----|-----|-----|
|        |     |     |     |      |     |     |     |
| Farm 1 |     |     |     |      |     |     |     |
| 1      | 0.10| 0.50| 0.15| 1.00 | 0.70| 0.42| 0.44|
| 2      | 0.09| 1.00| 0.15| 1.00 | 0.71| 0.33| 0.48|
| 3      | 0.08| 0.24| 0.15| 0.92 | 0.62| 0.78| 0.42|
| 4      | 0.89| 0.31| 0.98| 1.00 | 1.00| 1.00| 0.88|
| 5      | 0.10| 1.00| 1.00| 1.00 | 0.37| 0.59| 0.55|
| 6      | 0.12| 1.00| 1.00| 1.00 | 0.43| 0.64| 0.57|
| 7      | 0.08| 0.98| 1.00| 0.75 | 0.30| 0.83| 0.51|
| 8      | 0.15| 1.00| 1.00| 1.00 | 0.65| 0.98| 0.65|
| Farm 2 |     |     |     |      |     |     |     |
| 1      | 0.43| 1.00| 1.00| 1.00 | 1.00| 0.50| 0.75|
| 2      | 0.23| 1.00| 1.00| 1.00 | 1.00| 0.94| 0.74|
| 3      | 0.21| 0.77| 1.00| 1.00 | 1.00| 1.00| 0.71|
| 4      | 0.26| 0.32| 1.00| 1.00 | 1.00| 1.00| 0.68|
| 5      | 0.28| 0.65| 1.00| 1.00 | 1.00| 1.00| 0.72|
| 6      | 0.29| 1.00| 1.00| 1.00 | 1.00| 0.91| 0.75|
| 7      | 0.29| 0.94| 1.00| 1.00 | 1.00| 0.99| 0.76|
| 8      | 0.25| 0.32| 1.00| 1.00 | 1.00| 0.99| 0.67|
| 9      | 0.20| 0.28| 1.00| 1.00 | 1.00| 0.91| 0.64|
| 10     | 0.18| 0.24| 1.00| 1.00 | 1.00| 0.98| 0.64|
| 11     | 0.59| 0.61| 1.00| 1.00 | 1.00| 1.00| 0.82|
| 12     | 0.20| 0.24| 1.00| 1.00 | 0.98| 0.91| 0.63|
| 13     | 0.24| 1.00| 1.00| 1.00 | 1.00| 0.99| 0.75|
| 14     | 0.22| 0.47| 1.00| 1.00 | 1.00| 1.00| 0.68|
| 15     | 0.57| 0.34| 1.00| 1.00 | 1.00| 0.91| 0.77|
| 16     | 0.66| 1.00| 1.00| 1.00 | 1.00| 0.98| 0.89|

S1: soil index 1; soil indicators OC: soil organic carbon; P: phosphorus; K⁺: potassium; pH: potential of hydrogen in solution of H₂O 1:2.5; BD: bulk density; SSI: structural stability index.
Table S9. Results of soil index 2.

| Sample | OC | P   | K⁺  | Ca²⁺ | Na⁺ | Mg²⁺ | Al³⁺ | H⁺+Al³⁺ | m   | ESP | S2 |
|--------|----|-----|-----|------|-----|------|------|---------|-----|-----|----|
|        |    |     |     |      |     |      |      |         |     |     |    |
| Farm 1 |    |     |     |      |     |      |      |         |     |     |    |
| 1      | 0.16 | 0.00 | 0.00 | 0.00 | 1.00 | 1.00 | 1.00 | 0.00    | 1.00 | 1.00 | 0.52 |
| 2      | 0.11 | 1.00 | 0.00 | 0.00 | 1.00 | 1.00 | 1.00 | 0.00    | 1.00 | 1.00 | 0.61 |
| 3      | 0.08 | 0.00 | 0.00 | 0.00 | 0.60 | 1.00 | 0.20 | 0.39    | 0.00 | 0.00 | 0.23 |
| 4      | 0.75 | 0.00 | 0.00 | 0.00 | 1.00 | 1.00 | 1.00 | 0.20    | 1.00 | 0.00 | 0.49 |
| 5      | 0.15 | 1.00 | 0.00 | 0.00 | 1.00 | 1.00 | 1.00 | 0.00    | 1.00 | 1.00 | 0.62 |
| 6      | 0.22 | 1.00 | 0.00 | 0.00 | 1.00 | 1.00 | 1.00 | 0.00    | 1.00 | 1.00 | 0.62 |
| 7      | 0.09 | 0.52 | 0.00 | 0.00 | 1.00 | 1.00 | 1.00 | 0.00    | 1.00 | 1.00 | 0.56 |
| 8      | 0.27 | 1.00 | 0.00 | 0.00 | 1.00 | 1.00 | 1.00 | 0.20    | 0.81 | 0.00 | 1.00 | 0.53 |
| Farm 2 |    |     |     |      |     |      |      |         |     |     |    |
| 1      | 0.54 | 1.00 | 1.00 | 0.00 | 1.00 | 1.00 | 1.00 | 0.00    | 1.00 | 1.00 | 0.75 |
| 2      | 0.39 | 1.00 | 1.00 | 0.00 | 1.00 | 1.00 | 0.20 | 0.14    | 0.00 | 1.00 | 0.57 |
| 3      | 0.37 | 0.30 | 1.00 | 0.00 | 1.00 | 1.00 | 1.00 | 0.20    | 0.64 | 0.00 | 1.00 | 0.55 |
| 4      | 0.42 | 0.00 | 1.00 | 0.00 | 1.00 | 1.00 | 0.20 | 0.81    | 0.00 | 1.00 | 0.54 |
| 5      | 0.44 | 0.13 | 1.00 | 0.00 | 1.00 | 1.00 | 0.00 | 0.64    | 0.00 | 1.00 | 0.52 |
| 6      | 0.45 | 1.00 | 1.00 | 0.00 | 1.00 | 1.00 | 1.00 | 0.64    | 1.00 | 1.00 | 0.81 |
| 7      | 0.45 | 0.64 | 1.00 | 0.00 | 1.00 | 1.00 | 0.20 | 0.81    | 0.00 | 1.00 | 0.61 |
| 8      | 0.41 | 0.00 | 1.00 | 0.00 | 1.00 | 1.00 | 0.20 | 0.98    | 0.00 | 1.00 | 0.56 |
| 9      | 0.35 | 0.00 | 0.00 | 0.00 | 1.00 | 1.00 | 0.00 | 1.00    | 0.00 | 1.00 | 0.44 |
| 10     | 0.33 | 0.00 | 0.13 | 0.00 | 1.00 | 1.00 | 0.20 | 1.00    | 0.00 | 1.00 | 0.47 |
| 11     | 0.62 | 0.10 | 1.00 | 0.00 | 1.00 | 1.00 | 0.20 | 1.00    | 0.00 | 1.00 | 0.59 |
| 12     | 0.35 | 0.00 | 1.00 | 0.00 | 1.00 | 1.00 | 1.00 | 0.00    | 1.00 | 0.00 | 1.00 | 0.54 |
| 13     | 0.40 | 1.00 | 1.00 | 0.00 | 1.00 | 1.00 | 0.20 | 1.00    | 0.00 | 1.00 | 0.66 |
| 14     | 0.37 | 0.00 | 1.00 | 0.00 | 1.00 | 1.00 | 1.00 | 0.20    | 1.00 | 0.00 | 1.00 | 0.56 |
| 15     | 0.61 | 0.00 | 1.00 | 0.00 | 1.00 | 1.00 | 0.20 | 1.00    | 0.00 | 1.00 | 0.58 |
| 16     | 0.65 | 1.00 | 1.00 | 0.00 | 0.60 | 1.00 | 1.00 | 0.20    | 1.00 | 0.00 | 0.29 | 0.57 |

S2: soil index 2; soil indicators OC: soil organic carbon; P: phosphorus; K⁺: potassium; Ca²⁺: calcium; Na⁺: sodium; Mg²⁺: magnesium; Al³⁺: aluminum(III); H⁺+Al³⁺: potential acidity; m: saturation of exchangeable Al³⁺; ESP: exchangeable sodium percentage.

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