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Soil nutrient management in Haiti, pre-Columbus to the present day: lessons for future agricultural interventions

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Abstract

One major factor that has been reported to contribute to chronic poverty and malnutrition in rural Haiti is soil infertility. There has been no systematic review of past and present soil interventions in Haiti that could provide lessons for future aid efforts. We review the intrinsic factors that contribute to soil infertility in modern Haiti, along with indigenous pre-Columbian soil interventions and modern soil interventions, including farmer-derived interventions and interventions by the Haitian government and Haitian non-governmental organizations (NGOs), bilateral and multilateral agencies, foreign NGOs, and the foreign private sector. We review how agricultural soil degradation in modern Haiti is exacerbated by topology, soil type, and rainfall distribution, along with non-sustainable farming practices and poverty. Unfortunately, an ancient strategy used by the indigenous Taino people to prevent soil erosion on hillsides, namely, the practice of building conuco mounds, appears to have been forgotten. Nevertheless, modern Haitian farmers and grassroots NGOs have developed methods to reduce soil degradation. However, it appears that most foreign NGOs are not focused on agriculture, let alone soil fertility issues, despite agriculture being the major source of livelihood in rural Haiti. In terms of the types of soil interventions, major emphasis has been placed on reforestation (including fruit trees for export markets), livestock improvement, and hillside erosion control. For many of these interventions, there is limited independent, peer-reviewed data as to their success or long-term effect. By comparing soil interventions in Haiti with interventions that have been effective globally, we have identified several intervention gaps. The most important soil intervention gaps in Haiti include inadequate farmer training (extension) in soil management, and lack of technical support for legume and cover crops and for livestock pastures. We discuss the policy failures of different stakeholders working in Haiti, potential remedies, their costs, and likely long-term effects. We hope that this review will inform future efforts to improve soil fertility in Haiti.

Keywords: Haiti, Soil, Fertilizer, International development, Agriculture, Nutrition, Soil fertility, Erosion, Sustainable agriculture, Taino

Introduction

Haiti is one of the poorest and most food-insecure nations in the world. Of the country's population, estimated to be over 10 million, only 58% has access to an adequate amount of food [1,2]. Data suggests that 45% of Haitians are experiencing malnutrition [3]. In 2010, the only countries with a higher proportion of food insecurity were Eritrea, Burundi, and the Democratic Republic of Congo [1]. Agriculture is the primary income-generating activity for rural Haitians, who represent about 60% of the country's population [4]. In terms of production quantity, the top crops grown in Haiti (ranked in order) are sugar cane, cassava, yam, banana, sweet potato, plantain, maize, mango, guava, and rice [3]. It is estimated that only one-sixth of the land currently cultivated in Haiti is actually suitable for agriculture [5].

Haitian smallholders, who cultivate two hectares of land or less, have experienced a prolonged history of food insecurity, largely attributed to soil infertility and soil erosion [6]. In 1999, soil erosion in Haiti was estimated at 36 million tonnes, or 1,319 tonnes/km^2/year [7,8]; by contrast, the

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UK lost topsoil at a rate of 9 tonnes/km^2/year in 2004 [7,9]. There are intrinsic biophysical factors and anthropogenic factors that currently contribute to soil infertility and erosion in Haiti, including land gradient, rainfall patterns, soil types, and the unsustainable farming practices of impoverished smallholders [10,11].

The first biophysical factor contributing to soil erosion in Haiti is topography. On the Haitian portion of Hispaniola, approximately 75% of the terrain can be characterized as mountainous [12]. More than 60% of the land in Haiti has a slope gradient exceeding 20% [5]. Even without human intervention, Haiti's topography puts the soil at a naturally higher risk of erosion [13].

The second natural contributor to soil erosion in Haiti is its bimodal rainfall pattern. Haiti has a tropical climate with two rainy seasons, from April to June and from August to mid-November, which are interspersed with periods of drought [5]. Polarity in climatic conditions results in alternating extreme environments that can facilitate soil erosion either by wind during periods of moisture deficit, or by water during periods of intense moisture surplus [13,14]. Drought also causes soil crusting, which then leads to erosion upon the first heavy rains. The annual rainfall patterns in Haiti are poorly documented but appear to be as low as 300 mm in the northwest, and as high as 3,000 mm in the southwest [15,16].

The third biophysical contributor to soil infertility and erosion in Haiti is its soil type. Soil formation (pedogenesis) begins with long-term weathering of the underlying parent rock, which in Haiti is predominantly volcanic rock or limestone [17]. The formation of Haitian soils has resulted in one of four major subtypes (Figure 1), known as Udepts, Ustepts, Fluvents, and Udults [17]. Udepts and Ustepts are subtypes of Inceptisols; these are newly formed shallow soils that can support forests and grasslands, respectively. Fluvents are similarly shallow and also sandy, making them susceptible to the leaching of water-soluble nutrients. Fluvents are a subtype of Entisols, in which the rate of erosion exceeds the rate of soil formation. Fluvents consist of water-deposited sediments along rivers and of soils found in floodplains. Finally, Udults are a subtype of Ultisols, which are heavily leached acidic forest soils of low native fertility that require additional nutrients to support successful crop production [17]. In other words, the soils of Haiti are intrinsically fragile.

In addition to the above biophysical factors, soil infertility and erosion in Haiti have been accelerated by human activity, which has caused nutrient demand on farms to exceed the natural regenerative ability of the soils. In particular, the demand for fuel wood has perpetuated a process of deforestation, soil erosion, diminished crop yields, and subsequent food insecurity. With an

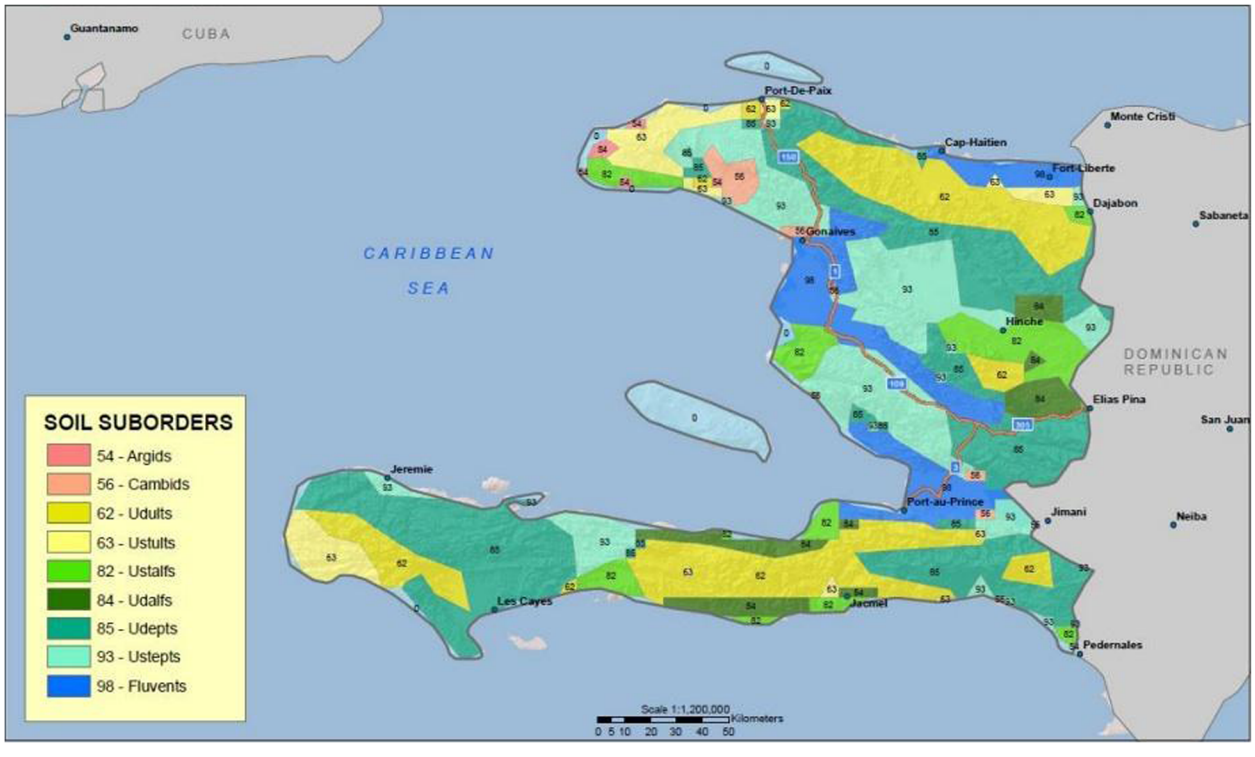

Figure 1 Soil map of Haiti.

average rural population density of 300 people per km^2, and 85% of the total population using fuel wood as a source of household energy (3.3 million m^3 per annum), the Haitian countryside has been left with only 3% forest cover [18]. It is estimated that charcoal production from wood is conducted on 21% of all farms [19], and a 2013 report suggests that this trend is on the rise [20]. As a secondary cause, from 1997 to 2003, the average farm plot size grew from 1.8 to 2.7 ha, which was caused by farmers clearing their land to increase the cultivation area in order to compensate for low crop yields on already depleted soils [18]. These findings demonstrate that forestry and farming are interdependent in Haiti. Deforestation causes soils to be exposed to wind and rainfall, which then accelerate the process of soil erosion [5,13].

In Haiti, lost soil minerals are not adequately replenished by synthetic fertilizers. Poverty in Haiti contributes to low fertilizer application rates, which results in a situation of near-zero mineral replenishment and an overall deficit in soil nutrients [21]. There is a stark difference between Haiti's recent consumption of nitrogenous fertilizers, at around 7,670 tonnes per year, and that if its neighbor, the Dominican Republic, at around 43,743 tonnes per year, despite Haiti having 31% more arable land [3,22,23]. For further comparison, the USA consumes 700% more nitrogen fertilizers per km^2 of arable land than Haiti [22]. There also appears to be a soil nutrient imbalance in Haiti, as the predominant fertilizer formulation used is 12-12-20 (nitrogen-phosphorus-potassium; NPK), creating a glut of potassium [5]. Researchers from the University of Florida tested 1,500 soil samples from Haiti's five major watersheds, and concluded that nitrogen is the limiting factor in plant production, followed by phosphorus [5]. Fortunately, the same soil survey (using 1,002 samples) found that the majority of sites had neutral to moderately alkaline pH (pH 7.0 to 8.2; 885 samples), with the remainder being acidic (pH 4.5 to 6.9; 117 samples) [5]. Most crops grow well in soils with a relatively neutral pH (approximately pH 5.5 to 8.0) [13].

Plants take up only a portion of added fertilizers, and the remainder can be leached or volatilized if they are not used as building blocks for living organisms in the soil that contribute to soil organic matter (SOM) [13,24]. SOM also consists of the partially decomposed residues of crops and any added manure that is rich in undigested plant feed such as straw [13]. Soils that are high in SOM feed microbes that are beneficial to crops (for example, mycorrhizal fungi that extend the root network). SOM can also benefit crops by providing a hospitable soil structure, and thereby improve the nutrient availability to crops, the drainage on clay soils (to reduce water-logging), and the water-holding capacity of sandy or sloping soils (to retain rainwater and prevent erosion) [13]. As SOM becomes diminished, greater quantities of synthetic fertilizers must be added, as their effectiveness is reduced by leaching and volatilization [13,24]. Unsustainable farming practices in Haiti that contribute to low SOM include removal of crop residues from the field, excessive tillage, lack of mulching, and lack of manuring [18]. A potential contributing factor to the lack of farmer attention paid to SOM may be insecure land ownership and lack of formal land ownership, as building of SOM is a long-term process and requires considerable investment over time. In Haiti, formal land ownership often exists on inter-personal or customary terms within a community, as opposed to formally written agreements via state systems [25,26]. Based on five separate large-scale surveys of land ownership in Haiti, researchers have estimated that farmer ownership of land, both formal and informal, ranges between 53% and 65% [27].

Livestock plays a particularly important role in building healthy soils by adding SOM through manure, as already noted, and as a source of labor for land preparation, essential for preventing soil erosion (for example, building soil ridges perpendicular to a slope). Data from the UN Food and Agricultural Organization (FAO) in 2011 showed that Haiti has only about 0.25 head of cattle per agricultural worker, compared with 2.7 and 2.8 in neighboring Dominican Republic and Cuba, respectively [28,29].

Validated strategies used to conserve soil fertility and prevent soil erosion

Before reviewing past and current efforts aimed at managing soil fertility and erosion in Haiti, it is important to briefly explain the relevant strategies that have been validated globally to combat these problems. These strategies include erosion control, use of organic fertilizers, effective use of synthetic fertilizers, and strategies to reduce the need for wood-based cooking fuel.

Several effective erosion-control strategies have been used around the world, based on the principles of conservation farming (CF) [30]. For example, rock-wall terraces have been effective in trapping sediment and blocking run-off, but are labor-intensive and cost-intensive to build and involve additional long-term repair costs [21,31]. Unlike rock barriers, living erosion barriers repair themselves naturally by re-growing. Living erosion barriers can include hedgerows of trees, shrubs, and grasses on slopes. An example of a holistic living barrier is vetiver *(Chrysopogon zizanioides)*, a non-invasive grass grown as a hedgerow that acts as a barrier to the forces of soil and water run-off, contributes to terracing, and can be used as a mulch [32]. Other well-known strategies include tied ridges (parallel ridges with interspersed mounds in the trenches to prevent water flow), contour farming (crops planted in rows perpendicu-

lar to the slope), and no-tillage agriculture (planting by seed drilling into existing crop residue without tilling the soil) [30,33]. A particularly effective strategy to prevent soil erosion is the use of cover crops, which carpet the soil, protecting it from exposure to rainfall within or between cropping seasons [11]. Perennial plants and trees serve a similar purpose, and alley cropping is a style of agroforestry that involves the cultivation of food crops between hedgerows of leguminous trees (see below) or shrub species [31,34].

The use of organic fertilizers has been shown to improve soil fertility. The oldest form of organic fertilizer is animal manure, which can be improved upon using appropriate composting, storage, and field-application strategies [35]. However, where livestock and poultry are limited, an alternative is vermiculture, the practice of raising earthworms for their feces (worm castings) [36]. Vermiculture has been shown to be a cost-effective source of organic fertilizer, although in practice, its application is limited to small home gardens [36]. Composting toilets are now resurfacing as an alternative technology to capture valuable nutrients from human waste, especially nitrates and phosphates [7,37,38], although this can be an expensive intervention in terms of capital costs.

The other crucial type of organic fertilizer is the nutrient-rich plant matter that remains in the field after harvest [39-41]. Of particular interest is plant matter that is rich in organic nitrogen, primarily legume crops (which are edible, for example, beans) and green manure plants (not edible by humans); these plants have a special symbiotic relationship with root-inhabiting bacteria that can convert atmospheric N_2 gas into organic nitrogen fertilizer [42,43]. Traditional cultures intercrop cereal crops (for example, corn) with legume crops, or rotate a cereal crop in one season with a legume crop in the next season; the non-harvested legume plant material (including roots) then deposits rich fertilizer into the soil during decomposition. The symbiotic nitrogen-capturing bacteria are known as Rhizobia, and different legume cultivars often require specific strains of Rhizobia for optimal production of nitrogen fertilizer [44]. Coating legume seeds with the optimal Rhizobia strain called an "inoculant" – along with the micronutrient molybdenum, if it is deficient in the soil – has been shown to improve legume yields and the deposition of organic nitrogen fertilizer into the soil [45].

Apart from organic fertilizers, smallholder farmers have benefited globally from strategies that improve the cost-effectiveness of commercial inorganic fertilizers. Commercial fertilizers are typically derived from mining, with the exception of nitrogen fertilizer, which is synthesized using natural gas. These commercial fertilizers are expensive, when applied by broadcasting across a field. Where farms are small and labor is cheap, 'microdosing' is a more cost-effective fertilization strategy, which involves placing small amounts of fertilizer (for example, using the cap from a soda bottle) beside each seed so that the fertilizer is targeted directly to the plant root zone and is not leached or volatilized [46-48]. Other strategies include: distributing synthetic fertilizers in affordable small packages rather than selling them in large bags; making available different formulations of the 14 nutrients required for crop growth (for example, 10-10-10, 20-15-5) to ensure that the fertilizer formulations will match the specific nutrient requirements of the crop(s) of interest; and using voucher programs to subsidize farmer access to fertilizers [43].

Finally, a number of solutions have been shown to help alleviate the problems associated with using wood for cooking fuel, which, as already noted, is a major contributor to deforestation and hence erosion in Haiti. Effective strategies in this area include: 1) the use of fast-growing trees such as eucalyptus and bamboo [49,50]; 2) sustainable tree-harvesting practices such as coppicing (tree regeneration from the tree base) [51]; 3) the use of more efficient cooking stoves (for example, the Kenya Ceramic Jiko Stove) [52]; 4) employing solar cookers, which use parabolic reflectors focused on a pot [53,54]; 5) promoting access to cooking oil produced from local crops (in Haiti, from peanuts and palm nuts) because the higher heat capacity of oil reduces cooking time, and hence the amount of cooking fuel required; 6) and the use of pressure cookers, which similarly minimize cooking time [55,56].

History of agricultural practices used in soil fertility and erosion-control interventions

In this section, we review a number of practices and interventions dating from pre-Columbian times to the present day, aimed at reducing the problems of soil infertility and erosion in Haiti, including efforts by non-governmental organizations (NGOs).

Indigenous pre-Columbian soil management practices

The indigenous people of Haiti, who inhabited the Island of Hispaniola before any Europeans or Africans, were known as the Taino. The Taino were related to people who crossed into North America from East Asia, and practiced a form of agriculture known as conuco [14,57]. Conuco were individual mounds of dirt on either sloped or flat land, laid out in rows, piled 0.7 meters high, and 2 meters in circumference [14]. Within these mounds, plant residues such as branches and leaves were embedded [57]. These residues provided high levels of SOM and loosened soil aggregates, resulting in improved water drainage and aeration, longer storage of mature tuber crops, easier weeding and harvesting, and reduced erosion [14,57]. In these mounds, many crops were cultivated, such as maize

and common bean (*Phaseolus vulgaris* L.); however, perennial tuber crops including cassava were the main pursuit of cultivation [14,57]. Conuco mounds could apparently stay in cultivation productively for 15 to 20 years, with a 30-year fallow period [14]. Taino agriculture is most remarkable for the fact that it supported a large population, estimated at anywhere between 1 and 8 million people, with individual settlements of around 5,000 inhabitants [14].

Another interesting practice in Taino agriculture was the cultivation of orchard gardens [14]. The Taino ensured regular groundcover with annual and perennial crop canopies, which further prevented erosion. Today, a healthy and diverse population of trees is recognized to have many benefits to soil: the root systems strengthen soil structure and promote microbial activity, while the tree canopy provides SOM through leaf litter [11,13].

Although not heavily adopted by the Taino, other pre-Columbian societies often constructed terraces on sloped agricultural lands to avoid losses of soil and nutrients [14]. A terrace system involves one or more embankments running perpendicular to the direction of the land's slope and acts to: 1) slow the speed of water flow, and 2) accumulate eroded soil particles and nutrients that can then begin forming a stable growth substrate [14]. A terrace creates cropland where it would not naturally exist [14].

As illustrated in the sections below, many of the sustainable farming practices of the Taino people are absent in modern Haiti, but why? Following the arrival of Europeans, it is estimated that more than 99% of the Taino population, or 3 million people, died within a 12 year period between 1494 and 1508, leaving a population of only 60,000 Taino [58]. This was due to violence, enslavement, and lack of biological resistance to European diseases. Europeans also introduced foreign livestock species, including the fast-running pig of the Spanish meseta, which over-populated the island and disrupted conuco mounds by digging up and eating many of the starch-rich tubers growing within [58]. European colonizers subsequently transformed the island from subsistence agriculture to plantation-style sugar-cane farming, and repopulated Haiti with African slaves who had agricultural traditions different from those of the Taino [58].

Modern farmer-derived practices: control of soil erosion

Despite historical upheaval and relocation, contemporary Haitian farmers created their own strategies to prevent soil erosion. Unfortunately, our literature review (see the following sections) suggests that very few foreign-led interventions have adopted, improved upon, or scaled up these grassroots practices, and in many cases do not have any knowledge of them, suggesting a lack of true partnership with local farmers.

One example is ramp pay (also known as rampe de paille or fascinage), which is a contemporary Haitian practice in which piled crop residues are placed along a contour (running perpendicular to the slope direction) and then covered with soil [10,59]. All of this is held in place by stakes in the ground [10]. Ramp pay uses the colluvial accumulating principles of a terrace, on a smaller scale, while also conserving moisture. It also has similarities to conuco mounds in terms of construction materials, making it a more affordable solution than large rock-walled terraces [10].

Another affordable solution that is sometimes combined with ramp pay by Haitian farmers is canal diversion (diversion ditches) [59]. A ditch 30 to 60 cm wide is constructed perpendicular to the land's slope, to trap hillside run-off, and runs at an angle of 1 to 3% in order to relocate water to proper drainage channels [59]. Even with rainfall shortages, canal diversion, along with other conservation structures, has been shown to increase yields of corn and sorghum by 22 to 51% and 28 to 32%, respectively, in the Maissade region of Haiti [10]. However, these ditches alone do not trap and retain the precious sediment that is continually being lost.

If sediment loss is not addressed before the run-off enters canal diversion (whether through ramp pay or some other method), some Haitian farmers trap the sediment later on in the drainage process through jardins ravine (alternatively known as clayonnage or kleonaj) [59,60]. This is a practical, local method of floodwater harvesting, which is different from rainwater harvesting in that the strategy works to capture both water and soil sediment. Canal diversion uses plant residues to construct barriers within gullies. These barriers act much like ramp pay to build up deposits of alluvium, which then become suitable for vegetable and fruit production [60].

Additional Haitian methods of soil management include zare, which involves forming soil and stubble into micro-catchments that hold water for rice cultivation [61], while sakle en woulo is a method in which, before planting, weeds are hoed into closely spaced, contoured ridges, which then trap run-off [61].

Modern farmer-derived practices: use of organic fertilizers

In addition to applying imported synthetic fertilizers that require institutional support (reviewed below), Haitian farmers also apply soil nutrients from self-derived, local organic sources, including manure (for nitrogen, phosphorus, and other minerals). Surprisingly, a recently published census [19] of around 1 million Haitian farmers did not include any questions about manure collection, storage, or application in Haiti, making it difficult to assess this valuable input. The survey, known as the Recensement Général de l'Agriculture (RGA; General Census of Agriculture), was conducted in 2008 to 2009 by the Haitian Ministere de

l'Agriculture des Ressources Naturelles et du Developpement Rural (MARNDR; Ministry of Agriculture, Natural Resources and Rural Development). In terms of potential manure sources, FAO data estimates that in Haiti in 2011 there were 1,910,000 goats, 1,455,000 cattle, 1,001,000 pigs, and 500,000 horses, with additional sheep and mules [28], a ranking that is consistent with RGA data [19]. However, 21% of surveyed Haitian farmers ranked decreasing soil fertility as their most severe obstacle to development, suggesting that manure availability is insufficient to support crops in modern Haiti [19]. Furthermore, 11% of surveyed Haitian farmers ranked animal diseases in their 'top 10' list of obstacles to development [19], suggesting insufficient veterinary care. A Web of Knowledge search [62] for peer-reviewed publications conducted using English or French terms for 'pasture' OR 'forage' AND 'Haiti' retrieved only one publication (from 1993) [63]; this paper examined goat and cattle feed and noted that, owing to a lack of soil fertilization, there were serious deficiencies in forages and animal phosphorus [63]. We found no peer-reviewed publications for 'manure' AND 'Haiti' in English or French, or for alternative sources of manure from worms (search terms 'vermiculture' AND 'Haiti'). These results suggest that there is very limited research in Haiti on manures and the factors that affect manure quantity and quality, namely animal diseases, pasture, and feed.

As noted earlier, the second major source of local fertilizer in Haiti is from crop residues of cultivated legumes such as beans [8,64-66], which are high in fixed nitrogen. RGA 2008 data suggested that legumes were cultivated by Haitian farmers on 26.5% of surveyed farmland, whereas FAO 2011 data estimated that legumes represented only 11% of the area harvested [19,28]; these different numbers require clarification. The RGA 2008 data further reported that the most widely cultivated legumes, in terms of land area, were the common (haricot) bean (*Phaseolus. vulgaris*) at 60%, followed by pigeon pea (Pois Congo; *Cajunus cajun*) at 26%), with unclear amounts of cowpea (black-eyed pea; *Vigna unguiculata*) [19]. By contrast, FAO 2011 data reported that 55% of land cultivated for legumes was for beans, 25% for cowpea, 15% for groundnut (peanut), and only 4% for pigeon pea. Clarifying this discrepancy is important in order to design appropriate interventions. For example, the residues of pigeon pea are high in both nitrogen and bioavailable phosphorus [67], and hence pigeon pea is ideal for the nutritionally poorest soils in Haiti, whereas cowpea is one of the world's most drought-tolerant legumes [67], and hence ideal for regions of Haiti known to suffer from drought. The United States Agency for International Development (USAID) Famine Early Warning Systems Network (FEWSNet) reported in 2013 that rainfall in some regions of Haiti was low or delayed by 30 days [20], demonstrating the need for drought-tolerant crops and crops that can produce grain earlier (short-duration varieties). Unfortunately, total production of cowpea and pigeon pea in Haiti has remained unchanged over 50 years, despite a concurrent doubling in human population [68]. Haitians with high dependency on the common bean may be suffering because this crop is much less drought-tolerant than the other three most widely grown legumes [67]. Traditionally, for Haitian smallholders, common bean, cowpea, and pigeon pea were intercropped primarily with maize, with lesser amounts of sorghum and pearl millet [11], the latter two being more drought-tolerant cereal crops.

We could find no peer-reviewed studies from Web of Knowledge [62], for cowpea or pigeon pea in Haiti, a result that perhaps explains the stagnation in legume production in Haiti. We retrieved only two papers for the terms 'crop rotation' OR 'intercrop' AND 'Haiti' [69,70]; these papers noted that diseases in common bean, along with low phosphorus in the soil, limit local legume production. The most important global institution for breeding of cowpea and pigeon pea, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in India, noted that Haitian cultivars of these crops were under-represented in their collection [71], which might inhibit efforts to introduce beneficial traits from around the world into Haitian legumes. We could not find any peer-reviewed papers [62] pertaining to selection or breeding of legumes for drought tolerance in Haiti, including the common bean. Furthermore, the terms 'seed bank' AND 'Haiti' returned no peer-reviewed publications in English or French in Web of Knowledge [62], suggesting that Haiti does not have a substantial seed collection for use in breeding programs that could be independently peer-reviewed.

Despite the fact that legumes are known to benefit significantly from inoculation with optimal strains of nitrogen-fixing *Rhizobium* bacteria and from addition of the micronutrient molybdenum [45], Web of Knowledge [62] searches yielded no peer-reviewed publications on these topics in Haiti.

Haiti could also benefit from cover crops that could prevent soil erosion during the dry season and at the onset of rainfall, especially a drought-tolerant green manure that could associate with *Rhizobium*. However, we retrieved [62] only two relevant peer-reviewed papers for the search terms 'cover crop' OR 'groundcover' AND 'Haiti,' and none for 'green manure' AND 'Haiti'. By contrast, we retrieved 702 papers for the terms 'cover crop' AND 'Canada,' and even 29 papers for 'cover crop' AND 'Honduras' [62], the latter being another poor, mountainous nation in the Americas.

As a final note on this topic, FAO data [72] estimated that maize (corn) is grown by Haitian farmers on 350%

more land area than the land used to grow all legumes combined, which is problematic because maize is a crop that requires substantial quantities of soil nutrients, especially nitrogen, for optimal growth. We could not find [62] any peer-reviewed studies on microdosing in Haiti, a cost-effective strategy to reduce the amount of synthetic fertilizer or manure required to grow crops such as maize [48]. Furthermore, farming practices for fertilization (types of formulations, timing, and rate of application) were not included in the RGA [19].

All of the above results show that there is a tremendous lack of authoritative knowledge on contemporary soil nutrient management practices in Haiti including peer-reviewed research to evaluate current aid interventions (for example, manure or legume improvement, fertilizers). We did find many project reports by aid agencies and governments (see below), but such reports are sometimes overly positive and not subject to independent review.

Haitian government soil interventions

In nations without a vibrant private sector, government agriculture departments have primary responsibility for training farmers, facilitated by agricultural 'extension officers'. Governments in such situations must also provide farmers with access to inputs such as seeds and fertilizers, enabled by short-term financial credit. In Haiti, these responsibilities lie with MARNDR. In general, our literature review suggests that there have been few truly MARNDR-led missions to restore local soils [2,31,73,74]. Despite hundreds of millions of dollars in donor aid flowing to Haiti over the past few decades, and despite agriculture being the primary source of income for at least 60% of Haitians [4], the RGA [19], conducted in 2008 to 2009, prior to the great Haitian earthquake of 2010, indicated major shortcomings under MARNDR's portfolio. For example, in a nation with around 1.5 million farming families [29], the RGA showed that only 3% of farmers had received one-time formal training (perhaps in the form of a workshop offered by an NGO) and less than 1% of farmers had received long-term technical training or university education [19]. These smallholders are also highly vulnerable, with only 20% having completed primary school [19]. Farmers themselves ranked the lack of farm training as the second largest barrier to development, after lack of financial resources [19]. The RGA also showed that farmers ranked, in their top 10 barriers to development, poor access to inputs such as fertilizers, lack of access to farm credit to purchase such inputs, diminished soil fertility, and increased erosion [19]. A 2013 report from FEWSNet [20] showed that the distribution of legume (and cereal) seeds met only 5 to 20% of local needs [20]. As noted above, legumes can supply organic sources of nitrogen fertilizer and thus reduce dependence on synthetic fertilizer imports. A 2010 Haitian government report [75] admitted that MARNDR supplied only 22% of required legume and cereal seeds, and only 12% of required fertilizers. It should be noted that seeds are not expensive, and despite receiving large sums of donor money, the Haitian government spent only USD $5 million in 2009 to purchase seeds for its approximately 1.5 million farming families [75].

Although some effective fertilizer subsidy programs have been implemented (see below), the above reports demonstrate that MARNDR has not succeeded at even inexpensive and simple projects, such as establishing sufficient local nurseries for legume (and cereal) seed multiplication, purchasing of diverse fertilizer formulations (including micronutrients, such as molybdenum, that are essential for biological nitrogen fixation), or making fertilizers affordable to farmers by selling them in small bags.

The detailed reasons for MARNDR's failures are beyond the scope of this review, but before the earthquake in Haiti, the Haitian government allocated only 7% of its 2009/2010 budget toward development in agriculture, whereas the FAO had suggested that this amount be increased to at least 12% [76-78]. In 2009, Fakuda-Parr analyzed data from the Organization for Economic Co-operation and Development (OECD), and determined that for 2007, only 2% of project aid in Haiti was allocated to the 'productive sectors' category [77]; interestingly, within this category, agriculture, forestry, and aquaculture were also included with mining, construction, and tourism. These figures are striking given that agriculture represents at least 28% of Haiti's gross national product, and at least 50 to 60% of total employment [78]. Other reported reasons for MARNDR's failures include: 1) tremendous volatility in donor funding (see below) [2], combined with high-priced foreign aid consultants [74]; 2) corruption, given that Haiti ranks among the top 10 most corrupt nations globally [79]; 3) political instability and top-down priority setting that does not match farmers' needs [21]; 4) high levels of ownership in the agriculture sector by the Haitian government [80]; 5) lack of private sector incentives and punitive farmer policies [80]; 6) a tradition of creating new institutions and commissions that look good on paper but are insufficiently funded [80]; 7) a disruptive influence at the local level by foreign NGOs that are often ill-informed about Haiti's agricultural needs [21]; 8) and inability by the Haitian government to coordinate the various foreign and domestic organizations working in Haiti, leading to inefficiencies, lack of scaling up, and low rates of adoption [21,73,74,81,82].

It is noteworthy that MARNDR recently requested USD $700 million in donor assistance to fund its new National Agriculture Investment Program (NAIP) in collaboration with FAO and Oxfam [83]. The NAIP donor

request demonstrates that the Haitian government, and/or its consultants, are well aware of the soil health needs of its farmers, as part of the plan allocates more than USD $140 million to purchase and subsidize fertilizers, including $10 million to build a storehouse for fertilizers to prevent against shortages and market fluctuations, funds to establish a National Fertilizer Service to optimize fertilizer formulation requirements, $2.8 million for seed multiplication, funds to optimize crop rotation, and $4.8 million for participatory agricultural extension [83]. For progress in livestock, a source of manure, the plan cites the importance of improved breeds and local feed sources [83], the latter of which recognizes past neglect in the area of pastures and livestock feed.

In spite of its failures, MARNDR has also had some notable successes: for example, thanks to its fertilizer subsidy policy, the total production of Haiti's staple cereal crop, maize (corn), increased by more than 70% from 2008 to 2011 [72,84]. However, nationally, the actual yield per hectare of maize increased by only 4% during this same period, and remained 16% lower than in 1961 [72,84]. In 2012, the Haitian government signed a Memorandum of Understanding with five companies to import three times more fertilizer than the previous year [85]. A promising pilot MARNDR program includes the Technology Transfer to Small Farmer Initiative (TTSF), intended to benefit 30,000 Haitian farmers at USD $900 per farmer, funded by the Inter-American Development Bank and the Gates Foundation's Global Agriculture and Food Security Program [86]. The project focuses on allowing farmers to select from a menu of 'technological packages' that improves pastures for the lowlands and hillsides, Creole garden regeneration for the hillsides and highlands, and intensification of annual crops (land preparation, improved seeds and pesticides for disease control) for flat lands [86]. The hillside Creole garden regeneration aspect of the project focuses on agroforestry systems (including coffee, cacao, and citrus), maize and bean intercrops, soil conservation, and sustainable natural resource management [86].

Haitian non-governmental soil interventions

There are 350 NGOs officially registered under the category of 'Haitian,' of which 33 include 'agriculture' as part of their official 'field intervention' [87]. Unfortunately, fewer than 10 of the officially registered NGOs working in areas of agriculture have functional English or French-language websites, and of those NGOs that have adequate websites, many of them do not articulate clear agricultural strategies. This partly explains the difficulty of knowing the breadth and depth of agricultural initiatives lead by Haitian NGOs. Nevertheless, in this section, we attempt to provide examples of direct or indirect agricultural soil interventions by key Haitian NGOs, regardless of their official registration status. However, it should be noted that according to separate UN data, there is an even greater variety of Haitian NGOs that, to varying degrees, are also operating in the area of soil fertility and erosion control (see Additional file 1; see Additional file 2).

First, Zanmi Lasante (Partners in Health), is a Haitian NGO that is well known for its numerous successes in public health in the Central Plateau of Haiti and other areas, and has expanded its operations to include agriculture with the creation of Zanmi Agrikol (ZA) in 2002 [74]. ZA has directly addressed the issue of deforestation relating to the consumption of fuel wood. ZA has encouraged reforestation with six operating tree nurseries, and has promoted the use of alternative energy technologies [88]. ZA promotes burning of the residues that remain after extracting the sugar from sugar cane in low oxygen, to create a charcoal powder called biochar [88], thereby recycling what was previously considered a waste product. Biochar can be combined with an adhesive (such as cassava juice) and compacted into small charcoal bricks that burn similarly to traditional wood charcoal [88]. Materials for the entire process can be sourced within Haiti, and this technology dually acts to reduce household spending and to generate income [88].

One of ZA's main objectives is to achieve high-levels of regional self-sufficiency in food production through a holistic, context specific, community-based approach [74]. ZA's Family Assistance Program (FAP) involves the provision of implements, seeds, saplings, livestock, and even land that is needed to increase local food production [74,88]. ZA also participates in the subsequent buying back of saved seed from the farmers, which assists in the expansion of the program's seed distribution efforts [74]. The FAP includes bi-weekly visits to the households by trained and paid community members acting as extension agents, to provide general support and to share agronomic knowledge and skills [74,88].

Another important NGO working in agriculture is Haiti's largest grassroots organization, Mouvman Peyizan Papay (MPP) [89]. MPP operates on a 9-year intervention cycle [49]. During the first 3 years of this cycle, MPP focuses on soil conservation, including an emphasis on biophysical erosion barriers and ravines [49,90]. MPP operates specific programs for women and adolescents, and its membership includes about 10,000 adolescents [90,91]. In the past, MPP has held 5 day 'Food Sovereignty and Environment' camps where adolescents learn how to plant trees and to make natural soil mixes, compost, and natural pesticides [91]. Tree nurseries and reforestation are a prioritized activity during the middle 3 years of the MPP intervention cycle [49]. As of 2005, MPP had planted over 20 million trees [92]. The final 3 years of the MPP intervention cycle focuses on income-generation solutions, including access

to agricultural credit [49,93]. MPP also has projects to reinvigorate the use of indigenous Creole swine breeds [92,94], which could be potential sources of manure. In 2005, MPP was awarded the largest global prize honoring grassroots environmentalism, the Goldman Environmental Prize [95,96].

The international NGO, La Via Campesina (LVC), which MPP helped to found, along with the Landless Workers' Movement (Movimento dos Trabalhadores Rurais Sem Terra; MST), have initiated 30-day agricultural training exchanges between Brazil and Haiti [97]. LVC and MST have established six seed centers in Haiti that produce and save seed from legumes and grains; they have begun reforestation efforts with avocado and mango trees; and have plans to open a technical-training school for young farmers [97]. These projects are funded by private Brazilian donors and Brazilian host families, and a Boston-based foundation called Grassroots International [97]. As part of its ongoing efforts, in 2011, LVC orchestrated an exchange of 76 young Haitian farmers to Brazil where they spent a full year learning about agro-ecology, soil and water conservation, social movement, organization, and farm cooperatives [98]. This type of agricultural training exchange would be even more effective if extended to government and NGO extension staff, in order to assist larger numbers of Haitian farmers.

Fonkoze is Haiti's largest microfinance institution and considers itself 'Haiti's Alternative Bank for the Organized Poor,' giving strong priority to rural women [74,99,100]. For example, Fonkoze has been extending credit to the Madame Saras, a group of 15,000 grassroots rural-urban traders, primarily women [100]. Even though Fonkoze has had only limited direct involvement with the soil conservation efforts of the farmers they represent, it still remains a noteworthy organization working at the grassroots level in rural Haiti. A majority of farmers (74.9%) surveyed in the RGA in fact cited a lack of access to credit as the primary barrier to farm development [19].

The Bassin Zim Educational Development Fund (BZEDF) is another Haitian NGO, founded by a Haitian agronomist who worked with MPP for 20 years [101]. Among its initiatives, BZEDF has a mandate to promote reforestation in Haiti. In 2009, after a slew of destructive hurricanes, BZEDF launched 'Seeds for Haiti,' which provides seeds (mostly corn and beans) in the form of a loan (valued at USD $23 per family) that must be repaid in kind after the first harvest in order to provide seed loans to other families [102]. Families also give a down-payment of 10% of the present value of the loan, which goes directly towards Seeds for Haiti's efforts to build the 'Seeds for Haiti Creole Seed Bank' [102].

As already noted, livestock provide benefits for soil fertility by producing manure that can be used to build SOM, which strengthens soil against erosion [103]. Veterimed, a Haitian NGO, specializes in livestock health and production in rural Haiti, and assists smallholders in animal husbandry [104]. Small-scale, household-based livestock production constitutes 90% of Haiti's livestock industry, but in 2005, there were only about 15 veterinarians in the country [104]. In the past, Veterimed has worked to establish Intervet (Entevet), a professional organization of 1,000 rural animal health workers [104]. Veterimed's projects focus on milk production, rabbits, goats, and poultry, because of their low environmental impact and high local market value [104]. The Haitian government, the UN Economic Commission for Latin America and the Caribbean (CEPAL), and the private sector have all recognized the success of the Veterimed model, which uses basic equipment and practical systems for the production, possession, and marketing of a sterilized milk brand, called *Let Agogo* [83,105]. Within this project, one of the key objectives is to promote sustainable resource management (grasses, forages, and water) [104]. Thanks to a Veterimed partnership with the Haitian Ministry of Agriculture, it is claimed that there are at least 2 to 3 veterinarian extension agents in each of the country's 567 municipalities [104]. This veterinary support network promises indirect benefits for the soil fertility on small farms through the increased presence of livestock. Haitian smallholders have cited a major need for improved livestock training and access to livestock disease prevention [19].

A major challenge in reforestation programs is that replanted trees are often cut down. Fruit trees represent a potential solution to this problem, as their major value comes from them not being harvested for wood. An NGO that has focused attention on fruit trees is the Organization for the Rehabilitation of the Environment (ORE), located in Camp Perrin of Southern Haiti's Sud province. Among a diversity of agricultural programs, ORE operates a laboratory used for tree propagation and research. With an annual budget of only USD $700,000 [2], ORE has a diversity of programs, including extending the production season of key nutritious and export-oriented fruit trees by introducing new cultivars (avocado, papaya, apple, and carambola). According to ORE, mango tree production has already been successfully extended using Coeur d'Or and Zillate cultivars [106]. ORE's laboratory work has also involved distribution and research of banana cultivars resistant to black Sigatoka, a fungus that is devastating banana production worldwide [107,108]. ORE has a mission: 1) to multiply, and distribute to farmers, sapling cultivars selected from international and local sources, and 2) to conduct research on these cultivars to improve their performance in the Haitian context [109]. Advanced agroforestry technologies for Haitian smallholders will undoubtedly benefit the reduction of deforestation-induced soil erosion.

Founded in 2006, Sustainable Organic Integrated Livelihoods (SOIL) is an NGO that attempts to promote the rehabilitation of Haitian soils through the recycling of human waste [38]. They aim to achieve this by enabling communities – those that have identified ecological sanitation as a priority – to convert human waste into nutrient-rich fertilizer [38]. In 2011, SOIL published, and began to freely distribute, the first edition of the *SOIL Guide to Ecological Sanitation*, designed to disseminate knowledge of the benefits and precautions of implementing composting toilet technologies [38].

The above examples illustrate that several grassroots Haitian NGOs, unlike many foreign organizations operating in Haiti, understand farmers' needs as voiced in the RGA [19], beyond just agroforestry, with projects to promote organic fertilizers from local materials, soil conservation (including erosion control), farm credit, improvement of livestock grasses and forages, veterinary extension, local breeding of improved plant cultivars, and distribution of legume seeds. Unfortunately, with the exception of well-known organizations such as Partners in Health, many local NGOs in Haiti are often unable to scale up effective agricultural interventions, perhaps because of inadequate coordination with the Haitian government and foreign NGOs, both of whom have been reported to be 'top-down' in their decision making, combined with volatility of donor dollars and the redirection of funds to consultants [2,74]. It has been reported that the organizations that suffer most from donor volatility in Haiti are the smaller NGOs. As noted by the UN, 'These organizations have relatively low financial capacities and are therefore obliged to develop their budgets and plan their activities for short periods (1 to 3 years). The smallest organizations remain dependent on an annual budgeting cycle…' [2].

Bilateral and multilateral interventions: past and present

Since 1990, at least USD $2 billion in official development assistance (ODA) has been given to Haiti, funding 70% of Haiti's federal budget [2]. In 2007, 70% of funding for Haitian NGOs came from the US and Canada. However, the actual amount of aid money that reaches Haitians on the ground is substantially less: one report alleges that 84% of every dollar spent by USAID in Haiti returns to the USA to pay the salaries of expert consultants [74]. Bilateral and multilateral funding has focused on urban security, urban infrastructure development, export-oriented manufacturing projects, and the creation of manufacturing 'free zones' in Haiti [78].

ODA fluctuations have had negative effects on the financing, continuity, and effectiveness of projects [2]. There was an increase in annual average ODA to Haiti between 1990 and 1991 (USD $174 million) under Haitian President Aristide, then a decrease between 1992 and 1993 (USD $112 million) under military rule, followed by an increase from 1995 to 2000 (USD $383 million), followed by a slump in ODA from 2000 to 2004 (USD $195 million) as a result of the disputed elections in 2000 [2]. Although ODA has been on the rise since 2004, even this has been sporadic, increasing by 93% in 2004/2005, and then increasing by 16% from 2005/2006 (by 2007 ODA was USD $701 million, making it worth 11.4% of Haiti's gross domestic product) [2]. Because any improvement in soil fertility is a long-term process, such volatility in financial assistance represents a significant challenge. Indeed, a 2010 United Nations Environment Programme (UNEP) analysis of 43 different environmental interventions in Haiti found that less than 20% of the interventions continued for more than 5 years [2].

How have foreign governments assisted Haiti in soil nutrient management? Notable bilateral agricultural interventions in Haiti began in the 1950s by addressing soil erosion with construction projects of either canals or rock-wall barriers; these programs were incentivized through temporary handouts ('food for work') rather than focusing on long-term community-based benefits [21]. In the 1980s, NGOs moved towards agroforestry programs with stronger participatory frameworks [21]. More specific agro-ecological mandates during the 1990s were to promote reforestation, conservation of remaining forests (for example, the Forest and Parks Protection Technical Assistance Project), and interventions across entire watersheds and catchment areas, specifically where parcels of land joined each other and were not scattered (for example, the Targeted Watershed Management Project, and Agriculturally Sustainable Systems and Environmental Transformation) [2,21]. One of the hallmark projects during this period was the 10 year USAID-funded Agroforestry Outreach Program (AOP; see below), which joined anthropologists with silviculture experts in order to address issues of soil infertility caused by deforestation [21,110].

The AOP was a joint venture between the implementing organizations (Pan American Development Fund (PADF) and Cooperative for Assistance and Relief Everywhere (CARE) Canada) and rural Haitian farmers, with the aim of improving local agroforestry systems. The organizations provided capital in the form of seedlings, and farmers contributed their labor and use of their land [110]. Trees were planted on land of which the farmers had secure ownership; in the first two years, 65 million seedlings were planted, and 300,000 farmers participated [110]. Relative to other afforestation projects, PADF reported a successful seedling survival rate of between 30% and 50% of planted trees [110].

The early 1990s Productive Land Use Systems project (PLUS) can be considered an offshoot of the AOP, and subsequently resulted in the Agroforestry II Project,

which continued and improved upon the outreach work of PADF. Agroforestry II offered a number of improvements to the groundwork laid out in the AOP. Extension work, initiated under the AOP, was modified with backyard nurseries, as opposed to larger regional nurseries. There was an emphasis placed on growing species of fruit trees, installing 'gully plugs' (to stabilize ravines by capturing run-off), installing both living soil erosion barriers (for example, vetiver grass) and residue-based barriers (for example, ramp pay), along with living erosion barriers designed to produce food with the barrier itself [21]. In 1995, PLUS's activities were absorbed into the USD $85 million Agricultural Sustainable Systems and Environmental Transformation (ASSET) programs, which included the Hillside Agriculture Program (both USAID-funded). Throughout the 1980s and 1990s, many of these types of projects were successfully partnered with local grassroots groups and saw moderate short-term success, but in general, 'project initiatives suffered from discontinuity of effort,' perhaps a result of inconsistent funding [2,21], as already highlighted.

The above projects suggest that many bilateral soil nutrient initiatives in Haiti have focused on agroforestry. The donation of saplings, and monitoring of their planting, are simple interventions for governments to quantify and verify, especially when there is skepticism regarding the transparency of local governments. In the big picture, however, have foreign funded reforestation projects succeeded in Haiti? Forest cover in Haiti has actually declined by 16% since 1990 [111], although the decline might have been steeper without these efforts. Replanted trees are often cut down because their only value to poor people is for fuel wood, in the absence of holistic interventions to alleviate poverty and improve fuel infrastructure. Therefore, in the context of soil nutrient management, the long-term results of some of the bilateral aid given to Haiti appear to be questionable.

Foreign non-governmental interventions

Today, there are an estimated 2,000 to 12,000 NGOs operating in Haiti [81], of which most are foreign, equivalent to up to one NGO per 1,000 Haitians, the highest concentration of NGOs in any nation. How did this happen? Haiti's unstable political climate in the 1980s began to foster a culture of low confidence in the Haitian government, which encouraged redirection of funds away from government and towards the civil sector. This contributed to a long-lasting rise in the number of foreign NGOs that operate in Haiti, and NGOs effectively became the implementing bodies for funds aimed at agricultural development [21,74]. Despite the large numbers of NGOs in Haiti, critical problems remain in 2013 -- problems that are widely reported and relatively simple and inexpensive to solve, such as creating nurseries to propagate legume seeds for planting [20]. Excellent grassroots farmer initiatives to prevent soil erosion, such as ramp pay (see above), have not been widely scaled up.

Part of the disconnection between foreign NGO interventions and farmers' needs may be due to language barriers, as Haitians speak French and Haitian Creole, whereas most people in the Americas speak English, Spanish, or Portuguese. Critical documents such as the RGA are printed only in French [19]. However, given the availability of online tools such as Google Translate, it would appear that the real problem is that foreign NGO personnel in Haiti often lack technical expertise and knowledge of Haitian farming practices, needs or local initiatives (such as MPP; see above), combined with inadequate coordination with MARNDR and with other NGOs. The proximity of Haiti to the USA and Canada has made it a target for many small charitable organizations and college students to visit for week-long trips that offer handouts and free foreign labor (for example, to build erosion barriers) – as unemployed Haitian watch; employing these same Haitian adolescents for the same tasks would benefit them and come at a lower overall cost. It has been argued that such practices by foreign NGOs have actually hindered long-term agricultural institution building; as one example, food handouts have caused waves of food price reductions in Haiti, preventing local food growers from selling at a fair market price [74]. When NGO funding or interest subsequently dries up, Haitians have been left even more dependent on foreign aid.

Rather than providing an exhaustive list of interventions that have not helped or damaged Haitian soils in the long term, in this section, we review a select list of reputable foreign NGOs operating in Haiti that appear to be doing promising work in the area of soil nutrient management:

World Vision has been running agricultural projects in Haiti since the 1970s, including its Sak Plen Resiliency Program across the Upper Central Plateau and Gonave Island, and the Enhanced Vegetable Crop Production project in Bassin Diaman [112,113]. World Vision has a project called the Program Development Zone that uses soil protection, tree planting, field cropping, livestock, and other agricultural income-generating/business activities as a mechanism for improving household nutrition [114]. World Vision has also implemented community gardens in Bordes and Balan (near Cap Haiten), and on Gonave Island [112]. Soil erosion in Anse-a-Galet on Gonave was particularly severe, so World Vision also introduced drip irrigation [112].

The Bangladesh Rural Advancement Committee (BRAC), the world's largest NGO, which is based in Bangladesh, is operating pilot projects in Haiti [115]. BRAC has created partnerships with local individuals and provided them

with the training and input needed to start a revenue-generating nursery of both fruit and timber saplings [115]. There are currently 150 of these nursery micro-franchises operating in the regions of Jacmel, Fondwa, Leogane, Ganthier, and Ponsonde, and 220,000 fruit and timber tree seedlings have been planted [115]. Similarly, BRAC has formed partnerships to create 200 poultry and livestock micro-franchisees, by providing the initial stock, inputs and training [115]; these are potential sources of manure. BRAC is also involved in the training of 'community agriculture promoters' to serve as role-model environmental stewards in their communities; a form of agricultural extension [116]. As of 2010, 56 of these agriculture promoters had been trained [116]. While BRAC places heavy emphasis on project ownership and expects participants to provide labor, land, and local knowledge, it cites extension as the reason for its high success rates [116]. Qualified field staff members pay weekly visits to the participants in order to observe each farmer's progress, to solve any problems, and to offer their technical expertise in agriculture [116]. BRAC's focus on extension services is highly commendable.

Rotary International has agricultural projects in Haiti that are dependent on the initiative of individual Rotary clubs in the various districts. Current information is not easily accessible, but there has been activity by Rotary districts relating to Haiti's soil problem. For example, Rotary clubs in South Carolina (district 7750) have contributed USD $300,000 over 4 years to ZA's FAP to provide irrigation, pumps, seeds, and grain-processing equipment [117]. Rotary clubs from Kansas and Illinois (districts 5690 and 6450) have introduced other Rotarians in Cap Haitien to solar oven technologies, which address the issue of deforestation [118].

Save the Children was involved in a historically important pilot watershed management project in Maissade, Haiti, during the 1980s. The project was funded by USAID, and is particularly noteworthy because it relied on building social capital through the creation of community-based farmer groups as the incentive to adopting soil conservation technologies (namely ramp pay and hedgerows) [119,120]. The area of intervention spanned over 22 watersheds (which averaged 9 acres in size), with 268 local participants, and attempted to construct 590 check dams to collect water and soil nutrients [119]. In 1989, plots treated with this intervention showed a 22% increase in corn yields and a 32% increase in sorghum yields [119]. The sustained benefits from this project, up to the present day, are uncertain [16,119,120]. However, soil moisture deficiency and lack of access to irrigation are cited by Haitian smallholders as major barriers to rural development, making the aims of this intervention commendable [19].

CARE has a history of being involved with agricultural projects in Haiti. From 1993 to 1996, CARE was involved in a project with USAID and PADF that involved on-farm trials with different cultivars of maize, sweet potato, and cassava, as well as cowpea and peanut [31]. As noted above, cowpeas and peanuts are legumes that contribute to soil fertility by depositing fixed nitrogen from symbiotic bacteria. The project aimed to identify beneficial yield and resistance traits in non-local cultivars of important crops [31]. The introduced cowpea cultivar was shown to have better yields and improved post-harvest resistance to pests [31].

At around the same time as the above project, CARE was the implementing agency for the USAID-funded AOP [21,110]. CARE has also been involved in current agricultural projects in the municipality of Gros-Morne, in the Artibonite province. Following the heavy destruction wreaked by the 2008 hurricanes, USAID provided funding for an emergency relief program in Gros-Morne, an area that was especially affected. Part of the intervention, with 50,000 intended beneficiaries, involved the rehabilitation of irrigation canals, construction of rock-wall erosion barriers, and distribution of seeds to farmers [121-123]. However, in the area of Riviere Mancelle in Haiti, local groups expressed concerns about rock-wall erosion barriers. They felt that the benefits from this method would be negligible because 'nothing was done in the river banks' [122].

Welthungerhilfe (also known as German Agro Action) has implemented 124 projects in Haiti, totaling around 60 million Euro, since its founding in the early 1970s [124]. Its work generally focuses on 'food security, irrigation and resource management as well as the supply of drinking water and an improvement in rural infrastructure' [124]. Welthungerhilfe currently operates in the north-west areas of Haiti. It is partnered with the World Food Programme (WFP), the International Fund for Agricultural Development (IFAD), and MARNDR [125]. Their activities in this region focus around the town of Jean Rabel, with a population of 10,000 and a surrounding population of 120,000 [125]. The organization aims to build walls and plant trees on 4,000 hectares of land, and to build irrigation systems on an additional 150 hectares [125].

Oxfam appears in part to be focused on sustainable rice production in Haiti, noting that 80% of Haiti's rice is now imported, in part due to local reductions in tariffs against imported rice, in addition to low levels of fertilizer use, poor crop varieties and low adoption of soil management technologies [126]. Oxfam has partnered with MARNDR, to support diverse projects including agroforestry as a form of reforestation, quality seed processing, improved tillage services, support for small livestock, restoration of river banks, soil conservation, distribution of inputs, and farmer credit and training, with partial funding from the Canadian International Development Agency (CIDA) [1,127].

In terms of learning about foreign NGO initiatives in Haiti, the reader is encouraged to view NGO websites and project reports, as new initiatives are constantly being launched and evaluated. Oxfam has recently summarized new NGO initiatives as well as bilateral programs to help Haitian agriculture [127].

Foreign interventions from the private sector

As noted earlier, the formal commercial private sector in Haiti is considerably underdeveloped, and further undermined by political instability and by free handouts from foreign agencies [74]. In the area of soil nutrient management, the formal private sector in Haiti appears to be tangential and often characterized by 'wish lists' rather than by successful companies, and by products designed for foreign rather than domestic consumers.

A limited private sector approach to soil rehabilitation in Haiti, focused on planting income-generating trees that could also prevent soil erosion, began in the 1990s under the USAID project PLUS [21]. The project included the introduction of improved cultivars of mango, one of Haiti's most important export tree crops [21]. Market-oriented strategies had an even stronger presence in the Hillside Agriculture Program (HAP), which ran from 2001 to 2005, and somewhat diversified to focus on trees including mango, coffee, and cacao [21]. NGOs such as Save the Children, CARE, and World Vision have also used such market-oriented strategies [21].

Coffee production has been an agricultural sub-sector of particular commercial interest, and is noted here because coffee tree plantations also have the ability to prevent soil erosion. Prior to the 1980s, the majority of Haitian coffee had been shade-grown, and the canopy helped to protect hillside agricultural systems from erosion [21]. However, owing to an international crisis in coffee prices during the 1980s and 1990s, coffee became less attractive to the Haitian smallholder [21], and from the 1980s until 2005, the amount of coffee exported by Haiti decreased by 80% [21]. This had a negative agroecological impact; some regions that were once known for widespread cultivation of coffee became known for having some of the most heavily eroded soils [21]. A partnership between Haiti's Federation of Coffee Producer Associations (FACN) and USAID has helped to bolster Haiti's vulnerable coffee crop, but farmers are still hesitant to return to coffee production because of a perceived risk of prices falling once again. A 2010 report from the World Economic Forum (WEF) suggested creating a credit line of USD $5 million for coffee producers in Haiti [4].

Moving forward, in 2010, the WEF estimated that from 2011 to 2016, the Haitian private sector will require USD $206 million for animal husbandry and USD $196 million for fruit and tuber production, including a need for further investments in mango trees [4], which, as noted, have the added benefit of preventing soil erosion. Haiti is the largest Caribbean supplier of mangos to the USA [4]. A particularly interesting investment opportunity may be vetiver grass. In 2010, USD $25 million was generated in revenue from export of processed vetiver aromatherapy products [4]. As described earlier in this report, vetiver grass has the additional benefit of providing soil erosion control.

The above review suggests that a significant gap exists within the private sector in Haiti in terms of not being able to take advantage of the defined needs of Haitian farmers [19], including failure to sell affordable commercial products that can improve soil nutrition, such as fertilizers, legume seeds, or improved farm implements. In such cases, extension agents could be useful by providing farmers with valuable market information, commodity prices and trends, and post-harvest storage methods to help the farmers sell products to cities. Of the female farmers surveyed in Haiti's RGA, 35.4% cited marketing difficulties as their greatest obstacle [19], demonstrating weakness in rural–urban trade. In the NAIP [19,83], the Haitian government appears to recognize the need to build rural markets and improve the flow of farm products to consumers, and also to ensure a better supply of inputs such as improved seeds and fertilizers.

A glimmer of hope, however, comes from the informal private sector in Haiti, in particular the Madame Saras (noted above) and the revendeuses, who are individual wholesale and retail traders, respectively [100]. The thousands of Madame Saras and revendeuses facilitate long-distance urban-rural trade in Haiti by purchasing food from family farms and selling them to cities. These traders and retailers, who are primarily women, have been referred to as the backbone of Haiti's market economy [100].

Summary

In this synthesis, we have reviewed intrinsic factors that contribute to soil infertility in modern Haiti, discussed effective farmer-led practices in contemporary Haiti, and provided a historical review of domestic and foreign interventions aimed at alleviating this problem. Several major themes have emerged. Intrinsic factors that contribute to soil infertility in modern Haiti include topology, soil type, and rainfall distribution, along with poverty and unsustainable farming practices. The pre-Columbian Taino people had a sustainable agronomic system (conuco mounds) to prevent soil erosion on hillsides – practices that appear to have been lost after colonization. However, in modern Haiti, farmers have developed a number of sustainable grassroots methods to combat soil erosion, although it would appear that many foreign NGOs are not aware of these practices.

There are a few effective grassroots NGOs in Haiti that are addressing the problems of soil infertility, including ZA, MPP, SOIL, Veterimed and ORE. Unfortunately, despite the fact that a significant majority of Haiti's population depends on agriculture for their livelihoods, only a small proportion of the thousands of NGOs appears to be directly targeting efforts towards agriculture including soil fertility [1,3,87]. In terms of the types of soil interventions, the primary focus of funding provided by large NGOs and bilateral, multilateral, and government agencies has been toward various reforestation projects including fruit trees for export, along with improved livestock and hillside erosion-control strategies. Unfortunately, for many of the projects, there are limited independent peer-reviewed data as to their success or long-term effect. Overall, there has been a failure to provide farmer training (extension services), seeds for planting (including drought-tolerant legumes), optimal fertilizers, or credit to purchase these inputs. In part, these failures may be due to the Haitian government allocating a disproportionally small percentage of its budget to agriculture (<2%). There are also claims that the majority of foreign aid does not reach Haitian smallholders, being used instead to pay foreign consultants, and that the remaining aid suffers from temporal volatility. Perhaps because of its proximity to North America, there has been a proliferation of small foreign NGOs in Haiti, which appear to lack technical expertise in agriculture and are disconnected from Haitian farming practices, needs, or local initiatives, and have apparently undermined local Haitian efforts. Furthermore, Haiti appears to lack a vibrant formal private sector in terms of affordable products that could benefit soil nutrient management.

The failures of the various stakeholders working in Haiti, including systemic failures to improve soils, are most evident from the following startling fact: despite all of the aforementioned interventions and the decades of donor aid, the problem of inadequate food supply in Haiti has remained virtually unchanged over approximately 60 years, increasing only slightly from 1,905 kcal/capita/day in 1961 to 1,979 kcal/capita/day in 2009 [4,128]. By contrast, the neighboring Dominican Republic has increased its food supply by 45% from 1,715 to 2,491 kcal/capita/day over that same period, despite having slightly higher population growth and the same total population as Haiti [129]. For further comparison, the food supply in the USA was 3,804 kcal/capita/day in 2009 [130].

Low soil fertility appears to have also affected food quality for Haitians. The total production of cereal crops such as maize has only increased by around 50% over the past 50 years in Haiti, despite a doubling in its human population during this period [84,131]. Cereal crops are protein-rich and require soils that are abundant in mineral nutrients such as nitrogen, which is a building block for protein. In contrast to cereal crops, cassava production increased four-fold in Haiti from 1961 to 2010 [132]. Cassava is an indicator crop of low soil fertility, which requires fewer soil minerals, and results in a starchy food that is low in protein. In other words, an increase in cassava production is a clear indicator of decreased soil fertility, increased malnutrition, and ultimately, increased poverty.

Recommendations for technical interventions

A large number of tree planting projects already exist in Haiti, warranting the expansion and diversification of Haiti's agricultural development toolkit. By comparing soil interventions in Haiti with interventions that have been effective elsewhere (see above and relevant references), we have identified numerous technical intervention gaps, the most important being inadequate farmer training (extension) in the area of soil management, and a lack of technical support for crops that could directly or indirectly enrich the soil. Below we identify 20 possible interventions.

In terms of farmer training, workshops that teach the following cost-effective methods may prove to be effective: 1) conservation farming principles, as exemplified by the ancient Taino people, that include preventing the soil from ever being bare, including the use of cover crops; 2) improved manuring/composting strategies to build up soil organic matter; 3) erosion control using living barriers grown from non-invasive grass seed; 4) tied-ridge land preparation to prevent soil erosion and promote *in situ* water and nutrient conservation; 5) cost-efficient fertilizer application strategies including microdosing; and 6) improved agronomic practices for legume-cereal intercrops (for example, optimized intercrop spacing to prevent leaf shading; improved crop rotation).

With respect to soil-enriching crops, Haitian farmers might benefit from technical support as follows: 7) establishment or improvement of a national seed bank to promote cultivar selection and breeding of legumes (plus cereals and vegetables), perhaps building upon the BZEDF Seeds for Haiti Creole Seed Bank (see above); 8) selection and breeding of legumes that require a shorter growing season and provide greater resistance to disease, pests and drought (cowpea is especially drought-tolerant and pest/disease-resistant); 9) selection of dry season weeds to produce candidate cover crops that have potential as nutritious animal feed, and that exhibit symbiotic nitrogen fixation to enrich soils and protect hillsides from erosion during the transition between the dry and rainy seasons; 10) establishment of nurseries to enable large-scale distribution of seeds, including for legumes and cover crops; 11) low-cost tools to help with seed planting, weeding and post-harvest processing in order

to reduce female drudgery; 12) improvements to pastures to improve livestock feed and subsequent manure, and to provide labor to support land preparation practices that promote CF, including indigenous practices to reduce erosion; 13) testing and sale of micronutrient fertilizers such as molybdenum, which in deficient soils can cost-effectively promote organic nitrogen production (nitrogen fixation) by legumes; 14) testing and sale of microbial inoculants (such as *Rhizobium*) to improve organic nitrogen production, optimized separately for the major Haitian legume cultivars; 15) testing and sale of effective pesticides for coating onto legume seeds prior to planting, to reduce costs and ecological damage associated with field spraying; and 16) low-oxygen storage bags (for example, GrainPro Superbag, Purdue Cowpea Storage Bag) to prevent pest damage to legume seeds (and cereal grains) during storage.

Additional areas that could benefit Haitian soils include: 17) making available smaller, more affordable bags of fertilizer rather than the current 100 lb bags; 18) improved access to appropriate fertilizer formulations optimized for each major crop; 19) vermiculture as an alternative source for local organic manure; and finally, 20) promotion of products that reduce cooking time such as improved cooking stoves, pressure cookers, and cooking oil from local plants. Of course, what is truly needed is an expanded national program to increase the availability of propane to replace wood as the major source for cooking fuel in Haiti.

The above ideas are only suggestions, and given the lack of large-scale data available on current Haitian farming practices and needs with respect to soil management, there is a need for detailed gender-distributed and age-distributed surveys to be undertaken first. In particular, Haitian farmers should be surveyed with respect to erosion-control measures (for example, ramp pay), manuring practices, fertilizer application rates and timing, cover crops, current legume cultivars and traits (for example, duration of growing season), and cropping systems (for example, crop rotation). Furthermore, given the lack of peer-reviewed research on Haiti, each of the above ideas should first be validated before any attempts at scaling up, for example, using split plots (adjacent control versus treatment subplots) on farmers' fields across multiple years, using participatory approaches, and followed by anonymous peer review.

Costs of implementing these recommendations

Many, but not all, of the above 20 proposed interventions were selected because they are cost-effective, ultimately leading to commercial products that farmers can afford to purchase themselves, making their success less dependent on centralized institutions and hence inherently scalable. For example, once available, locally propagated seeds of cover crops, pasture forages, grass-erosion barriers and drought-tolerant legumes can be produced at a few dollars per hectare, or farmers can produce their own seeds if they can be stored properly. The GrainPro storage bag for legumes can be purchased for USD $1 and is reusable [133]. *Rhizobium* inoculants cost USD $1.20 to $6 per acre, but can increase legume yields and nitrogen levels by 20 to 40% [134]. Coating of legume seeds with pesticides or molybdenum costs only a few dollars per hectare, because only small amounts of chemical are used compared with field spraying; for example, molybdenum applied at the rate of only 0.4 g per 100 g seed can increase yields of cowpea by 21% in soil deficient in this nutrient [135]. The practice of micro-dosing was shown to increase the value-to-cost ratio of synthetic fertilizers by up to 70% compared with normal broadcasting of fertilizer [48], and hence could reduce Haiti's substantial fertilizer subsidy bill. Improved cooking stoves such as the Kenya Jiko cost only USD $5 per stove (although can be as high as USD $23 for a Greenway Smart Stove) [136], but can save 300 to 600 kg of wood per family per year [137]. Other proposed interventions should not add to Haiti's existing fertilizer subsidy bill, such as making fertilizers available in smaller, affordable packages rather than 100 lb bags, or making a diversity of fertilizer formulations available.

Where assistance from the Haitian government or a large NGO would be needed is for initiatives such as establishing a national seed bank, starting a breeding program, or setting up a large-scale farmer training program (extension). The cost of establishing a seed bank or breeding program could be reduced by partnering with agriculture departments from neighboring Caribbean nations (for example, Cuba, Puerto Rica, Jamaica, Dominican Republic) or a Consultative Group on International Agricultural Research (CGIAR) breeding institute [138]. In terms of farmer training, we calculate that the operating cost to train Haiti's 1.2-1.5 million farming families [29] would be around USD $10 million per year, which would cover the salaries of 1,000 agricultural extension officers (salary USD $5000/year each; Haiti's gross national income is USD $650 per capita), and costs of internet, books, and motorbike fuel and maintenance. Each extension officer would be responsible for assisting 1,500 families (3 to 10 Haitian villages). A potential opportunity to reduce these costs and quickly implement a national extension program would be to train a subset of the ~15,000 Madame Saras in Haiti, as these grassroots urban-rural traders already have relationships with rural farmers especially women [100]. The promising USAID-funded Feed the Future program in Haiti has noted that it will explore the Madame Saras as information networks, noting that these women already supply farmers with inputs such as seeds and fertilizers [139]. The outcome of

any investments in training would be improved practices that are 'free' to farmers except for labor.

Policy suggestions for stakeholders to implement these recommendations

Implementation of the above recommendations will require co-operation and changes in policies from the various stakeholders in Haiti. With respect to the Haitian government, the literature strongly suggests that a much greater allocation of the federal budget is required for agriculture, including soil health, and to provide significantly higher funding for farmer training, with strategies focused on women and young people [75-78,83]. The median age in Haiti is 20 years, with 40% of the population being under the age of 15 years [15].

In terms of foreign governments, the literature suggests that much more stability in donor aid is needed [2,74,78], and that a much greater fraction should reach rural Haitians (around 60% of the population) rather than being spent on consultants [4,74]. Foreign aid is especially needed to scale up the efforts of grassroots Haitian NGOs, who have excellent solutions to prevent soil erosion, based on this review.

For the thousands of foreign NGOs operating in Haiti, it is clear that many foreign NGOs need to hire personnel with technical expertise in agriculture and soil management, and that they need to become more aware of local agricultural initiatives and attempt to partner with these groups, as well as with one another, rather than being "territorial". Some foreign NGOs also need to re-evaluate their interventions, such as week-long student projects, to ensure that their interventions are maximizing job creation for local Haitians and not undermining the private sector in the long term. To facilitate awareness of grassroots initiatives and partners, the Haitian government, specifically MARNDR could expand efforts to build online databases of grassroots organizations, projects, and contact information, in both English and French; hand out brochures at airports for arriving aid workers and students; and organize day-long orientation seminars for foreign aid workers that describe Haiti's agricultural history, Haitian farmer practices, projects, and stakeholders. The Haitian government may wish to consider more monitoring as to which NGOs should be allowed to operate in rural Haiti, based on their technical credentials.

With respect to the private sector, many opportunities exist in Haiti to sell a long list of affordable products that can improve soil nutrition (noted above) such as improved legume seeds, legume-coating agents, and legume storage bags. A formal distribution network for these low-cost products could be created rapidly by hiring Haitian experts who are already responsible for distribution of cigarettes and snack foods, which are distributed successfully by commercial stalls in rural Haitian villages. Products could also be sold on consignment to the Madame Saras and revendeuses [100] for distribution by Haiti's informal market supply chain.

Long-term effects of implementing these recommendations

Haiti's pre-Columbian history suggests that it is possible to sustainably support a large farming population when there is a strong emphasis on soil management [14]. Cuba and the Dominican Republic are countries that have invested in both urban industrial sectors and rural agricultural sectors as part of their development strategy [140-142]. Similar to successful rural development strategies currently being used in the emerging Southeast Asian nations [77,143,144], this dual approach seems to have been successful for the Dominican Republic and Cuba, since relative to other Latin America and Caribbean nations, both countries have been able to achieve relatively high levels of poverty reduction [145-149]. As noted earlier, whereas food availability in Haiti has stagnated over the past 60 years, it has increased by 45% in the Dominican Republic [4,129]. Haiti has considerably more arable land than the Dominican Republic, and compared with both Cuba and the Dominican Republic, a vastly higher proportion of Haiti's population is agrarian [3,23,150]. A vastly higher proportion of Haiti's population is also living in severe poverty, on less than USD $1.25 per day. Cervantes-Godoy and Dewbre [145] found that industrial development is more effective at reducing the poverty headcount among those living in the $2/day category, whereas agricultural development can be more effective at reducing poverty among the poor living at $1 to $1.25/day. Other researchers have reported similar findings [151-153]. Hence, proportionally, the long-term effect in Haiti of investments that promote agriculture and soil management may be even more positive than experienced by its neighbors in terms of alleviating poverty and improving human nutrition.

Additional files

Additional file 1: Key Haitian non-governmental organizations (NGOs) intervening in agriculture.

Additional file 2: Other Haitian non-governmental organizations (NGOs) intervening in agriculture: Office for the Coordination of Humanitarian Affairs (OCHA) provisional list.

Abbreviations

AOP: Agroforestry outreach program; ASSET: Agricultural sustainable systems and environmental transformation; BRAC: Bangladesh Rural Advancement Committee; BZEDF: Bassin Zim Educational Development Fund; CARE: Cooperative for Assistance and Relief Everywhere; CEPAL: United Nations Economic Commission for Latin America and the Caribbean; CGIAR: Consultative Group on International Agricultural Research; CIDA: Canadian International Development Agency; CF: Conservation

farming; CIDA: Canadian International Development Agency; FACN: Federation of Coffee Producer Associations; FAO: United Nations Food and Agricultural Organization; FAP: Family Assistance Program; FEWSNet: Famine Early Warning Systems Network; HAP: Hillside Agriculture Program; ICRISAT: International Crops Research Institute for the Semi-Arid Tropics; IFAD: International Fund for Agricultural Development; LVC: La Via Campesina; MARNDR: Ministere de l'Agriculture des Ressources Naturelles et du Developpement Rural (Ministry of Agriculture, Natural Resources and Rural Development); MPP: Mouvman Peyizan Papay; MST: Movimento dos Trabalhadores Rurais Sem Terra (Landless Workers' Movement); NAIP: National Agricultural Investment Plan; NGOs: Non-governmental organizations; ODA: Official development assistance; ORE: Organization for the Rehabilitation of the Environment; PADF: Pan American Development Fund; PLUS: Productive land use systems; RGA: Recensement Général de l'Agriculture (General Census of Agriculture); SOIL: Sustainable Organic Integrated Livelihoods; SOM: Soil organic matter; TTSF: Technology transfer to small farmers; USAID: United States Agency for International Development; WEF: World Economic Forum; WFP: World Food Programme; WV: World Vision; ZA: Zanmi Agrikol.

Competing interests
The authors declare that they have no competing interests.

Authors' contributions
RNB and MNR collaboratively designed the review, collected the data, analyzed the data, and wrote and edited the manuscript. Both authors read and approved the final manuscript.

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References
1. Cohen M: *Planting Now: Agricultural Challenges and Opportunities for Haiti's Reconstruction. Briefing Paper 140.* Oxford: Oxfam International; 2010.
2. Gingembre L: *Haiti Regenerative Initiative: Study of Lessons Learned in Managing Environmental Projects in Haiti. Country Report.* Port-au-Prince: United Nations Environment Programme; 2010.
3. FAOSTAT: **Haiti: country profile 2012.** [http://faostat.fao.org/site/666/default.aspx]
4. World Economic Forum: *Private Sector Development in Haiti: Opportunities for Investment, Job Creation and Growth. Report.* Geneva: WEF; 2011.
5. Hylkema AL: *Haiti Soil fertility analysis and crop interpretations for principal crops in the five winner watershed zones of intervention.* University of Florida, Institute of Food and Agricultural Sciences; 2011. Thesis.
6. Lewis LA, Coffey WJ: **The continuing deforestation of Haiti.** *Ambio* 1985, **14:**158–160.
7. Kulkarni C: *The Implications of Composting Toilets for Nitrogen Flows in Haiti. Final Report.* Providence: Brown University Center for Environmental Studies; 2009.
8. Jolly CM, Shannon DA, Bannister M, Flaurentin G, Dale JZ, Binns A, Lindo P: **Income efficiency of soil conservation techniques in Haiti.** In *Proceeding of the 26th West Indies Agricultural Economics Conference: July 2007; St. Augustine, Trinidad and Tobago.* Edited by Neela Badrie. Caribbean Agro-Economic Society; 2007:156–163.
9. Butler J: *UK Soil Degradation. Report no 265.* London: The Parliamentary Office of Science and Technology; 2006.
10. Lutz E, Pagiola S, Reiche C: **The costs and benefits of soil conservation: the farmer's viewpoint.** *World Bank Res Observ* 1994, **9:**273–295.
11. Zimmerman T: **Agroforestry – a last hope for conservation in Haiti?** *Agroforest Syst* 1986, **4:**255–268.
12. Bayard B, Jolly CM, Shannon DA: **The economics of adoption and management of alley cropping in Haiti.** *J Environ Manage* 2007, **84:**62–70.
13. Brady N, Weil RR: *Elements of Nature and Properties of Soil: Third Edition.* Upper Saddle River, NJ: Prentice Hall; 2010.
14. Whitmore TM, Turner BL: *Cultivated Landscapes of Middle America on the Eve of Conquest.* Oxford: Oxford University Press; 2001.
15. Swartley DB, Toussaint JR: *Haiti Country Analysis of Tropical Forestry and Biodiversity: Sections 118 and 119 of the Foreign Assistance Act. USAID Report.* Washington, D.C: United States Agency for International Development, United States Forest Service; 2006.
16. White TA, Runge CF: **Common property and collective action: lessons from cooperative watershed management in Haiti.** *Econ Dev Cult Change* 1994, **43:**1–41.
17. NRCS: *General Soils of Haiti. Map.* Washington: Natural Resource Conservation Service of the United States Department of Agriculture; 2010. ftp://ftp-fc.sc.egov.usda.gov/NHQ/pub/outgoing/soils/haiti_soil_suborders_map.pdf
18. Dolisca F, Carter DR, McDaniel JM, Shannon DA, Jolly CM: **Factors influencing farmers' participation in forestry management programs: a case study from Haiti.** *Forest Ecol Manage* 2006, **236:**324–331.
19. MARNDR: *Synthèse Nationale des Résultats du Récensement Général de l'Agriculture (RGA) 2008/2009. Government Report.* Damien: Composante de Statistiques Agricoles de Haiti; 2012.
20. Famine Early Warning Systems Network: **Haiti Food Security Outlook, June 2013 Report. Port-au-Prince:FEWS-Net; 2013.** http://www.fews.net/docs/Publications/Haiti_FSOU_2013_06_en.pdf
21. Smucker GR, Fleurantin G, McGahuey M, Swartley B: *Agriculture in a Fragile Environment: Market Incentives for Natural Resource Management in Haiti. Report No 521-000-05-00055-0.* Port-au-Prince: USAID; 2005.
22. FAOSTAT: **ResourceStat: fertilizers archive 2002.** [http://faostat3.fao.org/home/index.html#DOWNLOAD]
23. FAOSTAT: **Dominican Republic: country profile 2012.** [http://faostat3.fao.org/home/index.html#VISUALIZE_BY_AREA]
24. Marenya PP, Barrett CB: **State-conditional fertilizer yield response on western Kenya farms.** *Amer J Agric Econ* 2009, **91:**991–1006.
25. Smucker GR, White TA, Bannister M: **Land tenure and the adoption of agricultural technology in Haiti.** In *Innovation in Natural Resource Management: The Role of Property Rights and Collective Action in Developing Countries.* Edited by Meinzen-Dick R, Knox A, Place F, Swallow B. Baltimore: Johns Hopkins University Press; 2002:119–146.
26. White TA, Runge CF: **The emergence and evolution of collective action: lessons from watershed management in Haiti.** *World Dev* 1995, **23:**1683–1698.
27. Smucker GR, White TA, Bannister ME: *Land Tenure and the Adoption of Agricultural Technology in Haiti. CAPRi Working Paper No. 6.* Baltimore: International Food Policy Research Institute; 2000.
28. FAOSTAT: **Production: live animals, Haiti 2011.** [http://faostat.fao.org/site/573/default.aspx#ancor]
29. FAOSTAT: **Annual population, Haiti 2011.** [http://faostat3.fao.org/home/index.html#DOWNLOAD]
30. FAO: **Conservation agriculture.** [http://www.fao.org/ag/ca]
31. Shannon DA, Lea JD, Isaac L, Belfort S: *Technical Assistance to the Productive Land Use Systems (PLUS) Project: Final Report of the South-East Consortium for International Development (SECID) and Auburn University.* Washington, DC: USAID Haiti Economic Growth Office; 2001.
32. Truong P, Van TT, Pinners E: *Vetiver Systems Applications: Technical Reference Manual 2nd ed.* San Antonio: The Vetiver Network International; 2008.
33. Wiyo KA, Kasomekera ZM, Feyen J: **Effect of tied-ridging on soil water status of a maize crop under Malawi conditions.** *Agric Water Manag* 2000, **45:**101–125.
34. Isaac L, Wood CW, Shannon DA: **Decomposition and nitrogen release of prunings from hedgerow species assessed for alley cropping in Haiti.** *Agron J* 2000, **92:**501–511.
35. Rufino MC, Rowe EC, Delve RJ, Giller KE: **Nitrogen cycling efficiencies through resource-poor African crop-livestock systems.** *Agric Ecosyst Environ* 2006, **112:**261–282.
36. Misra RV, Roy RN, Hiraoka H: *On-Farm Composting Methods. Land and Water Discussion Paper 2.* Rome: United Nations Food and Agriculture Organization; 2003.
37. Balkema AJ, Preisig HA, Otterpohl R, Lambert FJD: **Indicators for the sustainability assessment of wastewater treatment systems.** *Urban Water* 2002, **4:**153–161.
38. Kramer S, Preneta N, Kilbride A, Page LN, Coe CM, Dahlberg A: *The SOIL Guide to Ecological Sanitation: First Edition.* Port-au-Prince: Sustainable Organic Integrated Livelihoods; 2011.
39. FAO: *Adaptation to Climate Change in Agriculture, Forestry and Fisheries: Perspective, Framework and Priorities. Interdepartmental Working Group on*

Climate Change Report. Rome: United Nations Food and Agriculture Organization; 2007.
40. Valentin C: **Soil crusting and sealing in West Africa and possible approaches to improved management.** In *Soil Tillage in Africa: Needs and Challenges. FAO Soils Bulletin 69*. Rome: United Nations Food and Agriculture Organization Information Division; 1993. Chapter 9.
41. Venkateswarlu B, Shanker AK: **Climate change and agriculture: Adaptation and mitigation strategies.** *Indian J Agron* 2009, **54:**226–230.
42. Vitousek PM, Cassman K, Cleveland C, Crews T, Field CB, Grimm NB, Howarth RW, Marino R, Martinelli L, Rastetter EB, Sprent JI: **Towards an ecological understanding of biological nitrogen fixation.** *Biogeochem* 2002, **57:**1–45.
43. Unkovich M, Herridge D, Peoples M, Cadisch G, Boddey B, Giller K, Alves B, Chalk P: *Australian Centre for International Agricultural Research (ACIAR)*. Canberra; 2008.
44. Perret X, Staehelin C, Broughton WJ: **Molecular basis of symbiotic promiscuity.** *Microbiol Mol Biol Rev* 2000, **64:**180–201.
45. N2Africa/Bill & Melinda Gates Foundation: *Putting Nitrogen Fixation to Work for Smallholder Farmers in Africa. Podcaster no. 8*. Wageningen; 2011.
46. Aune JB, Doumbia M, Berthe A: **Microfertilizing sorghum and pearl millet in Mali - agronomic, economic and social feasibility.** *Outlook Agric* 2007, **36:**199–203.
47. ICRISAT: *Fertilizer Microdosing: Boosting Production in Unproductive Lands*. Patancheru: International Crop Research Institute for the Semi-Arid Tropics; 2009.
48. Muehlig-Versen B, Buerkert A, Bationo A, Roemheld V: **Phosphorus placement on acid arenosols of the West African Sahel.** *Expt Agric* 2003, **39:**307–325.
49. Bannister ME, D'Agnes H, Gossin Y, Portnoff M, Smucker GR, Timyan J, Tobias S, Toussaint R: *Environmental Vulnerability in Haiti: Findings and Recommendations. Final Report*. Washington, DC: Chemonics International Inc., US Forest Service, United States Agency for International Development; 2007.
50. Pretty JN: **The sustainable intensification of agriculture.** *Nat Res Forum* 1997, **21:**247–256.
51. Thurston HD: *Slash/Mulch Systems: Sustainable Methods for Tropical Agriculture*. Boulder: Westview Press; 1997.
52. Hyman EL: **The strategy of production and distribution of improved charcoal stoves in Kenya.** *World Dev* 1987, **15:**375–386.
53. Funk PA: **Evaluating the international standard procedure for testing solar cookers and reporting performance.** *Solar Energy* 2000, **68:**1–7.
54. Porter K: **Final Kakuma evaluation: solar cookers filled a critical gap.** *Solar Cooker Review* 2004, **10:**2.
55. Kaygusuz K: **Energy services and energy poverty for sustainable rural development.** *Renew Sustain Energy Rev* 2011, **15:**936–947.
56. Oberascher C, Stamminger R, Pakula C: **Energy efficiency in daily food preparation.** *Intl J Consum Stud* 2011, **35:**201–211.
57. Rouse I: *The Tainos: Rise and Decline of the People Who Greeted Columbus*. London: Yale University Press; 1993.
58. Watts D: *The West Indies: Patterns of Development, Culture, and Environmental Change Since 1492*. Cambridge: Cambridge University Press; 1987.
59. Pellek R: **Contour hedgerows and other soil conservation interventions for hilly terrain.** *Agroforest Syst* 1992, **17:**135–152.
60. Critchley WRS, Reij C, Willcocks TJ: **Indigenous soil and water conservation: a review of the state of knowledge and prospects for building on traditions.** *Land Degradn Rehab* 1994, **5:**293–314.
61. White TA, Jickling JL: **Peasants, experts, and land use in Haiti: lessons from indigenous and project technology.** *J Soil Water Conserv* 1995, **50:**7–14.
62. **Thomson Reuters Web of Knowledge search database.** [http://wokinfo.com]
63. Veit HP, McCarthy F, Friedericks J, Cashin M, Angert R: **The relationship of Haitian small farm management to goat and cattle diseases.** *Rev Elev Med Vet Pays Trop* 1993, **46:**39–45.
64. Beaver JS, Rosas JC, Myers J, Acosta J, Kelly JD, Nchimbi-Msolla S, Misangu R, Bokosi J, Temple S, Arnaud-Santana E, Coyne DP: **Contributions of the bean/cowpea CRSP to cultivar and germplasm development in common bean.** *Field Crops Res* 2003, **82:**87–102.
65. McClintock N: *Regenerative Agriculture for Haiti's Central Plateau - A Sustainable Foundation for Food and Nutrition Security. NGO Report*. Paris: Zanmi Lasante; 2004.
66. Mortimore MJ, Singh BB, Harris F, Blade SF: **Cowpea in traditional cropping systems.** In *Advances in Cowpea Research*. Edited by Singh BB, Mohan Raj DR, Dashiell KE, Jackai LEN. Croydon: International Institute of Tropical Agriculture, Japan International Research Centre for Agricultural Science; 1997:99–113.
67. **International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) mandate crops.** http://www.icrisat.org/icrisat-crops.htm
68. FAOSTAT: **Production: crops, cowpeas, dry, Haiti (1961–2010).** [http://faostat3.fao.org/home/index.html#VISUALIZE]
69. Clermont-Dauphin C, Cabidoche YM, Meynard JM: **Diagnosis on the sustainability of an upland cropping system of southern Haiti.** *Agric Ecosyst Environ* 2005, **105:**221–234.
70. Clermont-Dauphin C, Meynard JM, Cabidoche YM: **Devising fertiliser recommendations for diverse cropping systems in a region: the case of low-input bean/maize intercropping in a tropical highland of Haiti.** *Agronomie* 2003, **23:**673–681.
71. Upadhyaya HD, Pundir RPS, Gowda CLL, Reddy KN, Singh S: **Geographical patterns of diversity for qualitative and quantitative traits in the pigeonpea germplasm collection.** *Plant Genet Res CharactUtil* 2005, **3:**331–352.
72. FAOSTAT: **Production: crops.** [http://faostat.fao.org/site/339/default.aspx]
73. Schuller M: **Invasion or infusion? Understanding the role of NGOs in contemporary Haiti.** *J Haitian Stud* 2007, **13:**96–119.
74. Zanotti L: **Cacophonies of aid, failed state building and NGOs in Haiti: setting the stage for disaster, envisioning the future.** *Third World Q* 2010, **31:**755–771.
75. MARNDR: *Plan d'Investissement pour la Croissance du Secteur Agricole: Production et Développement des Filières. Report Annexe 5*. Port-au-Prince: Ministere de l'Agriculture des Ressources Naturelles et du Developpement Rural; 2010. http://www.agriculture.gouv.ht/view/01/IMG/pdf/annexe_5.pdf
76. Bruemmer R: *PostMedia Network Inc*. Montreal; 05 June 2010. http://www2.canada.com/montrealgazette/news/saturdayextra/story.html?id=63a77e20-cb72-42f8-a825-fdf4a3700780
77. Fakuda-Parr S: *Empowering People: Human Rghts Review of Haiti's Poverty Reduction and Growth Strategies. An Issue Paper*. New York: The New School; 2009.
78. Shamsie Y: **Pro-poor economic development aid to Haiti: Unintended effects arising from the conflict development nexus.** *J Peacebuild Dev* 2012, **6:**32–44.
79. Transparency International: **Corruptions Perceptions Index (database).** [http://www.transparency.org/cpi2012/results]
80. **An economic and institutional analysis of soil conservation in Haiti.** In *Economic and Institutional Analyses of Soil Conservation Projects in Central American and the Caribbean*. Edited by Pagiola LE, Pagiola S, Reiche C. Washington: World Bank; 1994:98–106.
81. Morton AL: *Haiti: NGO Sector Study. Consultant Report*. World Bank: Washington; 1997.
82. OCHA: *Haiti: Cluster Partners Presence – Who What Where. Project Map*. Port-au-Prince: United Nations Office for the Coordination of Humanitarian Affairs; 2011. http://reliefweb.int/node/453665
83. MARNDR: *National Agriculture Investment Plan. Government Report (English Translation)*. Port-au-Prince: Ministère de l'Agriculture des Ressources Naturelles et du Développement Rural; 2010.
84. FAOSTAT: **Production, crops, maize,Haiti(1961–2010).** [http://faostat3.fao.org/home/index.html#VISUALIZE]
85. Thomas J: *300.000 sacs d'engrais de 100 livres disponibles sur le marché Haïtien dès cette semaine. Ayiti News (online newspaper)*. Port-au-Prince: EduMedia; 2012. http://ayitinews.com/300-000-sacs-dengrais-de-100-livres-disponibles-sur-le-marche-haitien-des-cette-semaine/
86. Brackmann S, Damais G, Etienne M, Garcia A, Jimenez J, Le Pommellec M, Martel P, Rodriguez A, Restrepo L, Salazar L: *Haiti: Technology Transfer to Small Farmers. Grant Proposal HA-L1059*. Washington: Inter-American Development Bank; 2011.
87. UCAONG: *Liste Actualisee des ONG Actives en Haiti. Government Report*. Port-au-Prince: Ministere de la Planification et de la Cooperation Externe et Unité de Contrôle et d'Administration des ONG; 2011.
88. Partners in Health: **Zanmi Agrikol.** [http://www.pih.org/support#history]
89. Mouvman Peyizan Papay: **About Mouvman Peyizan Papay.** [http://www.mpphaiti.org/-Qui-sommes-nous-.html]
90. Mouvman Peyizan Papay: **Programs, Agro-Ecology.** [http://www.mpphaiti.org/-Agro-ecologie-.html]

91. Mouvman Peyizan Papay: **Programs, Youth in action.** [http://www.mpphaiti.org/-Youth-in-action-.html]
92. Tramel S: *Haitian movements branch out. Huffington Post (newspaper).* New York: HPMG News Inc; 13 October 2011. http://www.huffingtonpost.com/salena-tramel/haitian-movements-branch-_b_1008807.html
93. Mouvman Peyizan Papay: **Programs, Economy and Cooperatives.** [http://www.mpphaiti.org/Economy-and-Cooperatives.html]
94. Notter DR: **The importance of genetic diversity in livestock populations of the future.** *J Anim Sci* 1999, **77:**61–69.
95. Goldman Environmental Prize: **Prize history.** http://www.goldmanprize.org/theprize/history
96. The Goldman Environmental Prize 2005: **Chavannes Jean-Baptiste.** [http://www.goldmanprize.org/2005/islands]
97. Patrola JL: **Haitian farmers and Brazil's landless workers' movement, 23 June 2011.** http://www.viacampesina.org/en/index.php?option=com_content&view=article&id=1069:belgium-international-days-of-action-for
98. Haiti Libre: **Haiti-agriculture: 76 young farmers trained in agro ecology returns home. Haiti Libre (online newspaper).** 9 October 2011. http://www.Haitilibre.com/en/news-3773-Haiti-agriculture-76-young-farmers-trained-in-agro-ecology-returns-home.html
99. Fonkoze: **Who we are.** http://www.fonkoze.org/aboutfonkoze/whoweare.html]
100. Rhodes L: **Haitian heroines: women are the backbone of Haiti's market system. But they need help – desperately.** *Intl Econ* 2001, **15:**38–42.
101. Bazelais J-B: **Letter from the president of Bassin Zim EDF.** http://bassinzim.org/who-we-are/letter-from-the-president-of-bassin-zim-edf/.
102. Bassin Z: **Seeds for Haiti: seeds bank.** [http://seedsforhaiti.org/]
103. de Haan C, van Veen TS, Brandenburg B, Gauthier J, Le Gall F, Mearns R, Simeon M: *Livestock Development: Implications for Rural Poverty, the Environment, and Global Food Security. Directions in Development Report 23241.* Washington: World Bank; 2001.
104. Veterimed: **Quid veterimed?** [http://www.veterimed.org.ht/]
105. CEPAL: *Let Agogo (Milk Galore) Programme to Support Milk Production, Processing, and Marketing in Haiti. Project Report.* Santiago: United Nations Economic Commission for Latin American and the Caribbean and the W.K. Kellogg Foundation; 2004.
106. Organization for the Rehabilitation of the Environment: **ORE's nutritional programs.**
107. Organization for the Rehabilitation of the Environment: **ORE's tissue culture program.** [http://www.oreworld.org/tissue.htm]
108. Mobambo KN, Gauhl F, Vuylsteke D, Ortiz R, Pasberg-Gauhl C, Swennen R: **Yield loss in plantain from black sigatoka leaf spot and field performance of resistant hybrids.** *Field Crop Res* 1993, **35:**34–42.
109. Organization for the Rehabilitation of the Environment: **About ORE.** [http://www.oreworld.org/aboutore.htm]
110. Bannister ME, Nair PKR: **Agroforestry adoption in Haiti: the importance of household and farm characteristics.** *AgroforestSyst* 2003, **57:**149–157.
111. FAOSTAT: *Resources, Land, Forest area 2011.* Haiti: United Nations Food and Agriculture Organization; Resources, Land, Forest area 2011 [http://faostat.fao.org/site/377/DesktopDefault.aspx?PageID=377#ancor]
112. Mazzeo J: **Laviche: Haiti's vulnerability to the global food crisis.** *Ann Anthropol Pract* 2009, **32:**115–129.
113. World Vision: **Haiti.** [http://www.worldvision.org/our-work/international-work/haiti]
114. Bassett L, Lamanna F, Ruel-Bergeron J: *Promoting Nutritional Security in Haiti: An Assessment of Pre- and Post-Earthquake Conditions and Recommendations for the Way Forward. Technical Assistance Report.* Washington: World Bank; 2010.
115. BRAC: **Haiti.** [http://haiti.brac.net/]
116. BRAC: *Haiti: Annual Report 2010.* Port-au-Prince: BRAC International; 2010.
117. Rotary International District 7750: **Partners in agriculture - Haiti.** [http://rotary7750.org/WCSprojects.asp#Haiti]
118. Sun Ovens International Inc: **Haiti update.** [http://www.sunoven.com/haiti-update]
119. White TA: *Peasant Initiative for Soil Conservation: Case Studies of Recent Technical and Social Innovations from Maissade, Haiti. Working Paper 11882.* St. Paul: USAID Environmental and Natural Resources Policy and Training Project; 1992.
120. White TA, Quinn RM: *An Economic Analysis of the Maissade, Haiti, Integrated Watershed Management Project. Working Paper 11878.* St. Paul: USAID Environmental and Natural Resources Policy and Training Project; 1992.
121. CARE: **Agricultural recovery project Gros Morne.** http://www.care.org/careswork/projects/HTI100.asp
122. Pierre M: *Agricultural Recovery in the Commune of Gros-Morne: Final Evaluation of the SYAP Project.* Port-au-Prince: CARE Haiti; 2009.123. CARE: Conservation agriculture – Gros Morne. http://www.care.org/careswork/projects/HTI114.asp
123. CARE: **Conservation agriculture – Gros Morne.** http://www.care.org/careswork/projects/HTI114.asp
124. Welthungerhilfe: **Our projects in Latin America – Haiti.** http://www.welthungerhilfe.de/latinamerica.html
125. World Food Programme: **Transforming agricultural land in the far west.** http://www.wfp.org/stories/transforming-agricultural-land-far-west.
126. Furche C: *The Rice Value Chain in Haiti. Research Backgrounder.* Boston: Oxfam America; 2013.
127. Joseph T: *Planting Now (2nd Edition). Revitalizing Agriculture for Reconstruction and Development in Haiti. Oxfam Briefing Paper 162.* Oxford: Oxfam International; 2012.
128. FAOSTAT: **Food supply 2009, crops primary equivalent, grand total, Haiti.** [http://faostat.fao.org/site/609/default.aspx#ancor].
129. FAOSTAT: **Food supply 2009, crops primary equivalent, grand total: Dominican Republic.** [http://faostat.fao.org/site/609/default.aspx#ancor]
130. FAOSTAT: **Food supply 2009, crops primary equivalent, grand total, United States.** [http://faostat.fao.org/site/609/default.aspx#ancor]
131. FAOSTAT: **Production, crops, paddy rice, Haiti (1961–2010).** [http://faostat3.fao.org/home/index.html#VISUALIZE]
132. FAOSTAT: **Production crops, cassava, Haiti (1961–2010).** [http://faostat3.fao.org/home/index.html#VISUALIZE]
133. GrainPro, Inc: **Quality preservation of dry agricultural commodities.** [http://www.grainpro.com]
134. Chianu JN, Nkonya EM, Mairura FS, Chianu JN, Akinnifesi FK: **Biological nitrogen fixation and socioeconomic factors for legume production in sub-Saharan Africa.** *Agron Sustain Dev* 2011, **31:**139–154.
135. Rhodes ER, Kpaka M: **Effects of nitrogen, molybdenum and cultivar on cowpea growth and yield on an oxisol.** *Commun Soil Sci Plant Anal* 1982, **13:**279–283.
136. Foote EM, Gieraltowski L, Ayers T, Sadumah I, Faith SH, Silk BJ, Cohen AL, Were V, Hughes JM, Quick RE: **Impact of locally-produced, ceramic cookstoves on respiratory disease in children in rural western Kenya.** *Am J Trop Med Hyg* 2013, **88:**132–137.
137. Barnes DF, Openshaw K, Smith KR, van der Plas R: **The design and diffusion of improved cooking stoves.** *World Bank Res Observ* 1993, **8:**119–141.
138. Consultative Group on International Agricultural Research: **CGIAR Centers.** [http://www.cgiar.org/cgiar-consortium/research-centers/]
139. *Feed the Future: Haiti FY 2011-2015 Multi-Year Strategy.* Washington: US Agency for International Development; 2011.
140. Bravo-Ureta B, Pinheiro E: **Technical, economic, and allocative efficiency in peasant farming: evidence from the Dominican Republic.** *Develop Econ* 1997, **35:**48–67.
141. USDA: *Cuba's Food & Agriculture Situation Report.* Washington: Office of Global Analysis, Foreign Agricultural Service, United States Department of Agriculture; 2008.
142. Valdes A, Foster W: **Reflections on the role of agriculture in pro-poor growth.** *World Dev* 2010, **38:**1362–1374.
143. Barichello R: *Agricultural development and poverty reduction in East Asia: The impact of OECD agricultural policies. Presented to the OECD Experts' Seminar on "The Impact and Coherence of OECD Country Policies on Asian Developing Economies": 10-11 June 2004; Paris.* Paris: Organization for Economic Co-operation and Development; 2004.
144. de Janvry A, Sadoulet E: **Agricultural growth and poverty reduction: additional evidence.** *World Bank Res Observ* 2010, **25:**1–20.
145. Cervantes-Godoy D, Dewbre J: *Economic importance of agriculture for poverty reduction. OECD Food, Agriculture and Fisheries Working Papers, No. 23.* Paris: Organization for Economic Co-operation and Development; 2010.
146. UNDP: *Human Development Report 1997: Human Development to Eradicate Poverty.* New York: United Nations Development Programme; 1997.
147. UNDP: *Human Development Report 2013: The Rise of the South.* New York: United Nations Development Programme; 2013.
148. UNDP: *Explanatory Note on 2013 HDR Composite Indices: Dominican Republic.* New York: United Nations Development Programme; 2013.
149. UNDP: *Explanatory Note on 2013 HDR Composite Indices: Cuba.* New York: United Nations Development Programme; 2013.

150. FAOSTAT: **Cuba: country profile 2012.** [http://faostat.fao.org/site/666/default.aspx]
151. Grewal BS, Ahmed AD: *Agriculture and poverty reduction: literature review and outstanding issues. Presented to the CSES International Workshop on the Role of Agriculture in Poverty Reduction. 6 May 2011.* Melbourne: Victoria University: Centre for Strategic Economic Studies; 2011.
152. Chen S, Ravallion M: **Absolute poverty measures for the developing world, 1981–2004.** *Proc Natl Acad Sci USA* 2007, **104:**16757–16762.
153. Thirtle C, Irz X, Lin L, Mackenzie-Hill V, Wiggins S: *Relationship Between Changes in Agricultural Productivity and the Incidence of Poverty in Developing Countries. DFID Report No. 7946.* London: Department for International Development (DFID); 2001.

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