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Business Sustainability & Improved Soil and Water Management Practices in Cocoa Production Systems.

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Abstract

This paper argues that it is critically important for the global cocoa and chocolate industry to promote smallholder farmers' adoption of 'improved' soil and water management practices (SWMPs), given that their capacity to adapt to and mitigate the impacts of increasing temperatures, changing precipitation patterns, and frequent extreme weather events on production directly impacts the vulnerability or resilience of the cocoa value chain to climate change. As the management of soil and water resources is typically constrained by policy, market, institutional and governance challenges, information asymmetries, and farmers' mindsets and levels of knowledge, this paper explores the extent to which the adoption and continued use of 'improved' SWMPs is contingent on farmers' perception of costs incurred relative to benefits derived. Taking the view that industry has a key role to play in enhancing the long-term sustainability of cocoa production against a backdrop of growing concern over climate change, and uncertainty regarding water availability and future climatic suitability of current cocoa growing areas, it offers original insights into how industry could facilitate farmers' adoption of 'improved' SWMPs. This paper argues that, in doing so, the industry could move towards closing the yield gap in a manner more compatible with its objective of realising 'climate-friendly' production; reduce its corporate ecological, carbon, and water footprint; adopt a sourcing strategy which is more ethical, and socially- and environmentally sustainable; and enhance its resilience and that of smallholder farmers - the primary link in the cocoa value chain - to climate change.

Introduction

One of the world's most important tree crops, cocoa (*Theobroma cacao* L.) provides a source of livelihood for an estimated 5-6 million smallholder farmers across Africa, Asia, Latin America, and the Caribbean (Edwin & Masters 2005; Franzen et al. 2007) and is a major contributor to the GDP of large producer countries such as Ghana and Cote d'Ivoire, and the export earnings of small producer countries such as Ecuador, Peru, and the Dominican Republic (Collinson & Leon 2000). However, as a cash crop produced primarily under rainfed conditions, its viability is threatened by changing precipitation patterns, increased temperatures, and the more frequent occurrence of extreme weather events such as floods and droughts (Läderach et al. 2013; Schroth, Läderach, et al. 2016). Production in some origin countries is already showing signs of being adversely affected 'from the time of planting to time of harvesting and drying' (Codjoe et al. 2013, p. 22).

Operating in an environment characterised by declining margins (ConfectioneryNews 2017a), and facing a scenario whereby profitability is determined by price elasticities and ratios relative to future market prices (ConfectioneryNews 2017b), the global cocoa and chocolate industry is slowly awakening to the fact that, given the consumption-side implications, in the long-run the 'burden of adjustment' cannot fall entirely on those responsible for cocoa production - namely, resource-poor smallholder farmers (Gilbert 2016). Although still exploring where its public responsibilities end and its corporate responsibilities commence (Lambooy 2011), the industry is increasingly accepting that it will need to devise long-term site-specific strategies to reduce farmers' sensitivity and exposure, and strengthen their capacity to adapt to the new reality of production against a backdrop of climate change (Gockowski & Sonwa 2011; Schroth, Jeusset, et al. 2016; Schroth, Läderach, et al. 2016).

As smallholder farmers have little incentive to improve the efficiency or effectiveness of water use until water availability becomes their main limiting factor (Hsiao et al. 2007; FAO 2012), this paper contends that the global cocoa and chocolate industry must take the lead in increasing the efficiency and effectiveness of water use. Although there is 'no such thing as average rainfall' (Faurès et al. 2010, p. 540), it posits that the sustainability of cocoa production will be contingent on the extent to which the industry manages climate risk and enhances smallholder farmers' ability to cope with increasingly variable precipitation patterns and expected future water scarcity (Adjei-Nsiah & Kermah 2012; Codjoe et al. 2013; Läderach et al. 2013b; ConfectioneryNews 2017c). Given that there is a direct relationship between conserving soil and water resources and increasing agricultural productivity and sustainability (Delgado et al. 2011; Abdulai & Huffman 2014), this paper argues the industry should encourage farmers to adopt improved soil and water management practices (SWMPs).

The remainder of this paper explores why cocoa is highly sensitive to water stress; why management of soil and water resources is key to increasing the sustainability of production; why smallholder farmers' willingness to adopt SWMPs is contingent on contextual factors; and why the industry could - by identifying and promoting context-specific improved SWMPs - not only address water scarcity, but also realise a more ethical, and socially and environmentally sustainable, 'climate friendly' sourcing strategy.

Methods

This paper is based on an analysis of peer-reviewed journal articles and grey literature, undertaken in the context of a 3-year PhD programme investigating the scope for soil and water management practices to increase the sustainability of cocoa production against the backdrop of climate change.

Discussion

Highly sensitive to water stress during its juvenile, growth, and development phases (de Almeida et al. 2016), cocoa is exceptionally demanding in its soil requirements and most productive when cultivated in well-drained soils (Asare et al. 2016). As a shallow rooting crop, it cannot easily access lateral water resources or access vertical soil moisture reserves and can only tolerate soil water deficit conditions for short periods of time (Zuidema et al. 2005; Köhler et al. 2010; Carr & Lockwood 2011; dos Santos et al. 2014). Although roots lengthen to access water and nutrients, and the roots-to-shoot ratio increases, periodic water stress results in a net solute accumulation in the roots, which reduces osmotic potential and cell turgor, and inhibits leaf and shoot growth and the production of flowers (Zuidema et al. 2005; Moser et al. 2010; dos Santos et al. 2014). Biomass allocation under conditions of water stress is initiated and yield is adversely impacted (Carr & Lockwood 2011).

Currently, 70% of variation in annual yield is explained by precipitation during the two driest months of the year and radiation over the course of a year (Zuidema et al. 2005), with the impact of water stress being greatest when exacerbated by drought conditions (Schwendenmann et al. 2010; dos Santos et al. 2014). By 2050, however, cocoa yields will be determined as much by smallholder farmers' ability to manage the impacts of heat stress on production as by their ability to manage drought stress (Schroth, Läderach, et al. 2016). Higher maximum dry season temperatures will induce premature and increased leaf senescence and abscission, and lead to a decline in the leaf area index (LAI) of cocoa trees. While low LAI will positively impact cocoa by reducing the evapotranspiration requirement of a production system (Zuidema et al. 2005), it will adversely impact the capacity of the crop for evaporative cooling under drought conditions (Peh et al. 2015; Ayegboyin & Akinrinde 2016).

Against a backdrop of water scarcity, stemming more from the variability of rainfall and excessive non-productive losses than total annual precipitation in the growing season (Biazin et al. 2012), crop breeding will likely play an increasingly important role in reducing the impact of water stress on cocoa production by improving photosynthetic water-use efficiency (WUE) throughout the lifecycle of the crop (Condon et al. 2002). To date, research has focused on establishing the correlation between genotypic variation in WUE and specific leaf area (Daymond et al. 2011), the impact of temperature on photosynthesis under conditions of elevated CO_2 (Balasimha et al. 1991), and the impact of elevated CO_2 on WUE (Lahive et al. 2017). As water is also lost from cocoa production systems through non-stomatal transpiration and soil evaporation, future research will also need to identify and exploit the constitutive and adaptive traits driving the effective use of water (EUW) (Blum 2009).

In addition to promoting drought-tolerant clones and cultivars for adoption based on the findings of ongoing research on tolerance to water and drought stress, the global cocoa and chocolate industry will need to improve smallholder farmers' management of the assets on which cocoa production relies for success - namely soil and water resources (Pretty 2008). Soil water deficit stems from the variability of precipitation patterns, but is exacerbated by unfavourable soil conditions (Zuidema et al. 2005; Keil et al. 2008). To address the root cause of soil water deficit, the industry will therefore need to identify and promote improved SWMPs, i.e. practices which improve soil water holding capacity of a soil and increase its water content by improving infiltration and drainage, aeration, and reducing the extent to which runoff and leaching occurs (Franzluebbers et al. 1995; Rice & Greenberg 2000; Zuidema et al. 2005; Keil et al. 2008).

Currently, 50% of rainfall from rainfed crop production systems is lost to evaporation, surface runoff, and drainage, and only 10-30% is used in crops transpiration (Wallace 2000; Biazin et al. 2012). This suggests that there is considerable scope to 'upgrade' rainfed cocoa production (Falkenmark et al. 2001) and that it is time for the global cocoa and chocolate industry to embrace the concept of integrated rainwater management (Rockström et al. 2003). Although it has historically regarded irrigation as a water management option only worth adopting by smallholder farmers after all other factors limiting cocoa production have been addressed (Carr & Lockwood 2011), the industry should promote irrigation using rainwater and surface runoff harvested in-situ and ex-situ, as it could increase the volume of water availability in the rootzone for uptake by 30% and contribute towards rehabilitating degraded soils, thus creating a wetter landscape, more conducive to production (Dile et al. 2013).

As the soil water balance of a cocoa production systems is a product of four factors, namely infiltration, root water uptake (influenced by evapotranspiration), downward redistribution of water, and external drainage (dos Santos et al. 2014), the global cocoa and chocolate industry should encourage smallholder farmers to construct micro-catchment systems (pits, contour ridges and furrows, terraces, earth bunds, and micro-basins) and macro-catchments (open ponds, cisterns, micro-dams, sand dams, and spate-irrigation systems), and engage in water harvesting to improve the spatial and temporal distribution of water (Rockström et al. 2010; Biazin et al. 2012;). Reducing the amount of rainfall lost through unproductive evaporation, litter and canopy interception, and runoff, water harvesting would improve the efficiency of rainwater use in cocoa production (Biazin et al. 2012; Bulcock & Jewitt 2013).

While the quantity of water concentrated, collected, stored, and available for use in irrigating cocoa will be determined primarily by smallholder farmers' choice of rainwater harvesting system, and by landscape conditions (Bulcock & Jewitt 2013), there is a need to support smallholder farmers in identifying and establishing the most appropriate irrigation system (traditional surface, modern surface, sprinkler or drip) based on the infiltration characteristics of their production systems, i.e. the depth which water reaches and the rate at which soil moisture is depleted, advances, and recedes (FAO 1989; Pereira et al. 2002). As irrigation systems differ in the level of control and flexibility offered over inflow rate and cut-off time, and over the delivery schedule, i.e. discharge rate, duration (volume) and frequency (timing), farmers' choice will determine whether or not distribution uniformity and application uniformity are realised (FAO 1989; Pereira et al. 2002).

In addition to adopting rainwater harvesting and irrigation, smallholder farmers should be encouraged to engage in soil conservation, as the quantity, depth distribution, quality, and turnover rate of organic carbon directly influences the water holding capacity and water transmission characteristics of a soil (Franzluebbers et al. 1995; Gurtner et al. 2011; Biazin et al. 2012; Lal 2015; Utomo et al. 2016). Mulching, weeding, addition of organic amendments and fertiliser application, conservation tillage, cover crops, windbreaks, vegetative strips, and long-term incorporation of shade trees in cocoa production systems will positively impact soil fertility and quality, as well as the structure and functional diversity of the soil biological community responsible for decomposing organic matter and binding soil particulates – including organic carbon - into aggregates (Unger et al. 1991; Abawi & Widmer 2000; Bronick & Lal 2005; Powlson et al. 2011; Koch et al. 2013).

As smallholder farmers have historically not been regarded as stakeholders in the arena of soil and water conservation (Fairhead & Scoones 2005), the extent to which they are actively conserving soil and water resources is currently undocumented and unknown. Although not perceiving climate change in the same way as climatologists (Maddison 2007), farmers engaged in cocoa production are aware of climate change. Rather than being passive victims of climate variability, they are switching from cocoa to drought resistant crops such as maize and cassava, adopting cultivars with short vegetative cycles, and establishing seedbeds rather than undertaking semi-direct seeding of cocoa (Gyampoh et al. 2009; Adjei-Nsiah & Kermah 2012; Comoé et al. 2015). Recognising that yields are declining, and that it is difficult to replant cocoa in an environment which is considerably more degraded and drier, farmers are also diversifying production to include rubber production (Schroth & Ruf 2014).

Although aware of their exposure to the impacts of climate change and already perceiving water scarcity as a threat to cocoa production, it is likely that smallholder farmers will only be willing to adopt improved SWMPs if practices promoted by the global cocoa and chocolate industry do not act as a catalyst for further exposure to the impacts of climate change (Vignola et al. 2010). To ensure that practices are context-specific, and that interacting climatic and non-climatic stresses do not render farmers' adoption ineffectual or even maladaptive, the industry will need to work closely with farmers to explore how the risk posed by climate change is perceived. Rather than focusing on and assuming a priori that climate change is the sole (or main) issue of consideration, the industry will also need to take into consideration how farmers perceive the conditions under which they produce cocoa, in general, to be changing (Westerhoff & Smit 2009).

Given that smallholder farmers are motivated to maximise net income rather than increase the productivity of water use, a farmer-oriented approach will need to be adopted towards identifying and promoting improved SWMPs (Neilson & McKenzie 2016). This will ensure that farmers are not discouraged from adopting practices by their lack of knowledge as regards on-farm water-efficiency, crop water use, and the likely yield response to water management practices such as irrigation (Levidowa et al. 2014). Moreover, as adoption of practices hinges on local knowledge being reconciled with scientific knowledge, the industry will need to engage in continuous knowledge-exchange, and move beyond reiterating standard technical production advice to giving farmers a more voice and recognition in the process of initiating and implementing agricultural research (Kolawole 2013; Levidowa et al. 2014; Berlan in preparation).

Taking a strategy-centric rather than stakeholder-centric approach, the global cocoa and chocolate industry has to date been largely unsuccessful in driving a shift towards more sustainable cocoa production practices through technology transfer programmes (Neilson & McKenzie 2016). Regarding smallholder farmers as passive recipients of technology, rather than key players in identifying, analysing, designing, and implementing research activities (Dormon et al. 2004), the industry has looked to improve farmers' technical competency to achieve greater output with a limited level of inputs and technologies (Binam et al. 2008), while failing to realise that 'technical aspects of production are deeply embedded in contexts which also need to be understood' (Berlan in preparation, p. 24). As Ayenor et al. (2004, p. 262) observe, technology adoption has been undermined by 'the linear process and top-down approaches taken towards [its] development and dissemination in the first place'.

Despite testing, evaluating, validating, adapting, and reinventing practices in a manner bearing semblance to the methods utilised by researchers engaged in adaptive agronomic work (Sumberg et al. 2003), smallholder farmers have traditionally not been involved in the technology development and transfer process (Kolawole 2013). As adoption is a dynamic learning process which encompasses uptake, intensification, innovation, spread, abandonment, and replacement of practices (Vellema & Van Wijk 2015), and involves farmers moving from acceptance to actual adoption and continued-use of practices (de Graaff et al. 2008), the global cocoa and chocolate industry will need to engage with farmers' views on soil and water conservation – even if these views are couched in moral, religious, mythical or superstitious ideas – to identify economically-viable and socio-culturally acceptable improved SWMPs (Fairhead & Scoones 2005).

As Sietz & Van Dijk (2015, p. 137) observe, there is 'no small set of universal drivers that systematically explains the adoption of soil and water conservation measures'. Smallholder farmers' decisions to engage in the conservation of soil and water resources are either intrinsic, based on the perceived return on investment, or as a result of the provision of an incentive. They adopt practices based on their ability to acquire the capital and labour resources, information, and skills required, and their ability to access to credit services and extension systems, and leverage social networks (Boyd et al. 2000; Knowler & Bradshaw 2007; Bagdi et al. 2015; Musiyiwa et al. 2016; Hunecke et al. 2017). Influenced by group dynamics, farmers adopt practices based on the amount and type of social capital which they possess, and how strong the effects of social capital and norms are relative to their risk aversion (de Graaff et al. 2008; Wossen et al. 2015).

Resilience to climate change is a product of the contextual and institutional environment in which the process of adaptation occurs (Curry et al. 2015). Consequently, the global cocoa and chocolate industry will need to ensure that it creates an enabling policy and institutional environment, and engages in an education and awareness-raising drive to stimulate conservation action by users of soil and water resources, i.e. individual smallholder farmers and their communities (Shiferaw et al. 2009). In doing so, the industry is likely to achieve more than merely partial success, as measured by observed rates of adoption of practices, unlike intervention in other agricultural sub-sectors (de Graaff et al. 2008). Promotion of practices for adoption by farmers engaged in cocoa production will not be undermined by 'extreme poverty and imperfect market factors, inadequate property rights systems, and weak organizational and institutional arrangements at different levels' (Shiferaw et al. 2009).

As climate change but more specifically future water scarcity threatens to undermine the viability of cocoa production, the global cocoa and chocolate industry will need to identify and promote practices which have the capacity to improve soil moisture retention, reduce soil loss, and increase yields (Tenge et al. 2005; Bagdi et al. 2015; Neilson & McKenzie 2016). Table 1 outlines practices, some of which are not traditionally thought of being associated with cocoa production but are widely used in the production of crops other than cocoa, and which could, if context-appropriate, potentially be promoted by the industry as improved SWMPs. Of the practices listed in Table 1, one practice which highlights the challenge that the global cocoa and chocolate industry will face in encouraging smallholder farmers to adopt improved SWMPs is agroforestry production, or the incorporation of shade trees in a cocoa production system.

Table 1: Potential SWMPs in cocoa production

Category of SWMP	Objective	SWMP	Reference
Water harvesting	Water concentrated, collected, stored and conveyed for irrigation purposes or Water flow diverted or improved to increase infiltration, and reduce surface runoff	Rainwater harvesting	(Gyampoh et al. 2009)
		Micro-catchments	(UNDP 2015)
		Earth barriers	(Wood & Lass 2008)
		Bunds	(Wade et al. 2010; Conservation Alliance 2013; Kolawole 2013; UNDP 2015; Udawatta et al. 2017)
		Shallow surface drains	(Wood & Lass 2008)
		Trenches	(Wood & Lass 2008)
		Drainage dykes/ditches	(Wood & Lass 2008)
		Underground clay pipes	(Wood & Lass 2008)
Irrigation	Water application controlled to realise facilitate greater application efficiency and distribution uniformity or Water and fertiliser applied simultaneously to address nutrient deficiencies, and realise yield benefits stemming from increased water availability	Motorized pump-and-pipe irrigation	(IWMI 2014)
		Drip irrigation	(Wood & Lass 2008)
		Trickle irrigation	(Wood & Lass 2008)
		Micro-sprinkler irrigation	(Wood & Lass 2008)
		Fertigation	(Krishnamoorthy & Rajamani 2013; Krishnamoorthy et al. 2015)

Soil conservation	Soil evaporation reduced to minimize non-productive water losses or Temporal and spatial dynamics of soil water controlled, to maximise water availability and uptake by crop or Soil fertility and quality restored, to reduce erosion and increase soil water holding capacity	No planting on steep slopes	(UNDP 2015)
		Contouring	(Asare & David 2011; Asare 2014; UNDP 2015; Udawatta et al. 2017; Wartenberg et al. 2017)
		Vegetative strips	(Asare 2014)
		Cover crops	(Asare 2014)
		Mulching	(Asare & David 2011; Asare 2014; Conservation Alliance 2013; Kolawole 2013)
		Fertiliser application	(Wood & Lass 2008; Asare 2014)
		Soil amendments	(Kubi-Tetteh 2015)
		Planting density	(Wood & Lass 2008)
		Weeding	(Wood & Lass 2008)
		Pruning	(Wood & Lass 2008)
		Agroforestry production (shade trees)	(Anglaaere 2005; Oke & Odebiyi 2007; Deheuvels et al. 2012; Utomo et al. 2016; Schroth, Jeusset, et al. 2016)
		Clearing riparian vegetation	(Gyampoh et al. 2009)
		Pesticide / Insecticide application	(Asare 2014)

Although agroforestry production is more sustainable than full-sun production – providing a buffer against climate variability (Schroth et al. 2001; Köhler et al. 2010; Tscharntke et al. 2011; Utomo et al. 2016) and replicating a natural forest closed system as regards water cycling (Lin et al. 2008) – farmers are increasingly moving towards eliminating or limiting shade trees to intensify cocoa production and increase productivity (Vaast et al. 2016). As Ruf (2011, p. 376) observes, if agroforestry production is to 'have a future in the twenty-first century, […] [the practice] will need to be reinvented through dramatic technical, economic and institutional changes'. More information guidance must be provided on optimum tree cover (Mbow et al. 2014), in addition to information on selection, spacing and spatial arrangement of shade trees, and pruning to reduce shade at critical times in the production cycle (Vaast et al. 2014).

Conclusion

Climate change and future water scarcity threaten to undermine the long-term sustainability and viability of cocoa production in current cocoa-growing areas (Läderach et al. 2013; Schroth, Läderach, et al. 2016). Given that consumers are increasingly calling for more ethical and both environmentally and socially sustainable sourcing strategies (Newton et al. 2013; Chkanikova & Mont 2015), there is a business imperative for the global cocoa and chocolate industry to support smallholder farmers in adopting a more sustainable, 'climate-friendly' model of cocoa production (Schroth et al. 2011). While adaptation to climate change is often considered more pertinent than mitigation (McCarthy 2001), given that there is a nexus between the hydrological and carbon cycles (Jarecki & Lal 2003; Lal 2004; Lal 2009), the industry will be in a position to both adapt to and mitigate climate change provided it supports farmers in conserving soil and water resources and, specifically, in adopting improved SWMPs.

As Pretty (2008) observes, enhancing agricultural sustainability implies making better use of available resources, practices and technologies. Given that smallholder farmers will only adopt improved SWMPs if the potential benefits derived (i.e. increased production, reduced labour input, higher off-farm income) are outweighed by the costs incurred (de Graaf et al. 2008), the global cocoa and chocolate industry will need to move beyond 'business as usual' and adopt a more farmer-oriented approach to knowledge exchange and to technology development and transfer (Kopnina 2015; Neilson & McKenzie 2016). This paper demonstrates that the industry will only be in a position to increase the sustainability and viability of future cocoa production, its own resilience, and that of the cocoa sector as a whole, if it strengthens farmers' livelihood security by encouraging the adoption of improved SWMPs which are context-appropriate and which do not translate into environmental degradation, sub-optimal use of soil and water resources, and inequity in access to likely scarce future water resources (FAO 2012).

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