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# Systems thinking creates opportunities for a circular economy and sustainable palm agriculture in Africa

Palm agriculture has received strong criticism in recent years due to its link with deforestation, especially in Asia. Here we propose that there is instead an opportunity for sustainable palm futures in Africa. Applying interdisciplinary systems thinking and circular production models, food and economic security can be achieved sustainably by (i) promoting integrated production of nutritionally valuable insect and fungal protein using palm crop waste; (ii) increasing resilience and productivity of crop palms in the harsh tropical climates of sub-Saharan Africa; and (iii) promoting the development of palm plantations as biodiverse agroforestry ecosystems.

Climate change is accelerating and will affect crop production and food security worldwide. With growing populations and changing expectations, it is estimated that food production must increase by 60–110% by 2050 (Cui et al., 2018). To achieve this, it is acknowledged that rather than continued agricultural expansion, the solutions will be to increase crop efficiency, shift diet and reduce waste (Foley et al., 2011). Given the expected climatic changes, agricultural technologies should target improving drought and salinity resistance in the medium term (Godfray et al., 2010). To deliver a sustainable food provision in tropical areas, efforts should also concentrate on smallholder farmers, who produce and depend-upon on local crops (Cui et al., 2018). In this context, palms are keystone species in tropical ecosystems and provide essential services to rural communities. In Africa, however, it is estimated that palms will not cope with the predicted 2080 climate over 70% of their current productive range, and that 42% of this decline will happen in highly populated regions where palms currently contribute to sustainability (Blach-Overgaard et al., 2015).

Palms will be part of Africa's future, but there is a need to bridge the gap between research and development as well as to integrate on-the-ground use and applications. Coconut palms are an extremely popular crop, with over 60 million tonnes of nuts produced annually by 90 countries across the globe (2689 l oil/ha) (source FAO, e.g. (Killman, 2001)). The top three producers are in Asia (Indonesia, Philippines, India, with 3 million tonnes of nuts produced annually), followed by Brazil, but Africa is rapidly expanding its market share. West tropical Africa is gaining on its rivals in Asia, with, for example, Ghana planning one million hectares of coconut plantation, which will employ more than 200,000 people to deliver expected revenues of 12 billion US dollars per year (Ghana Investment Promotion Centre, 2019). Côte d'Ivoire, currently the leading African coconut exporting country, has similar ambitions, with a current income of up to 7.5 thousand US dollars per hectare of plantation on rich soils and 4 thousand US dollars per hectare on poor soils (source CNRA). Oil Palms are one of the world's most rapidly expanding crops and the primary source of vegetable oils in food, cosmetics, pharmaceuticals and fuel. Nigeria, Ghana, and Côte d'Ivoire are the most important African producers of palm oil. With current fresh fruit bunch yields of 20–22 t/ha/year, oil palm can deliver 1.6–1.8 thousand US dollars in revenue per hectare annually in these regions (source CSIR). Climate change is, however, expected to affect oil palm productivity in West Africa severely by 2030. The area likely to be suitable for current oil palm varieties is also predicted to decline dramatically by 2050, with 70% of highly suitable land in Nigeria estimated to be lost (Paterson et al., 2017). Although the environmental impacts of oil palm plantations need to be mitigated, it is a more efficient oil crop than any other (e.g. soybean: 500 l oil/ha/an versus oil palm 5950 l oil/ha/an) and world demand for oil palms continues to increase.

Palm cropping in Africa is industrialising and is increasingly led by fewer large companies rather than by many smallholder farmers. There is thus a need to provide new models to nudge practice and ensure that commercial African palm agriculture develops more sustainably than in much of Asia. Two long-standing and increasingly promoted approaches can contribute much here: (1) applying interdisciplinary systems thinking in which social and economic systems are viewed as nested within, and dependent upon, natural systems (Williams et al., 2017); and (2) moving from current linear pathways to models of circular economy in which cyclical materials flows can offer paths to efficient use and re-use of former 'wastes' (Jurgilevich et al., 2016) (Fig. 1). A study of the life cycle of palm crops highlights several currently missed opportunities (Fig. 1).

Intercropping and waste recycling are common agroforestry practices carried out by smallholders and these have many benefits, including weed control, food provision, improvement of soil physico-chemical properties, secondary revenue, etc. Modifying the spacing of trees within larger plantations can add layers to income generation through enhanced intercropping and increasing ecosystem service provisions (Fig. 2). For example, banana, soybean, peanut and cowpea can be intercropped with coconut palms for about 10 years before the palm canopies affect production, providing additional income ranging from one thousand (cowpea) to 4.5 thousand US dollars (banana) per hectare. Maize, cassava and plantain can be intercropped with oil palms, initially planted around 1 m away from the palm trees, but with increasing distances as the palm grows and fronds spread. Four to five years after establishment, oil palm canopy growth shifts intercropping to shade-tolerant species such as climbing peppers. This can provide important additional food crops and revenues in these regions, from about 1.5 thousand US dollars per hectare (maize) to possibly 9.4 thousand US dollars annually (cassava). Studies of palm intercropping remain few relative to those of other agroforestry systems and cash crops, but have been shown to improve the livelihoods of smallholder farmers and reduce weeding costs in Ghana and Cameroon, as well as buffering their incomes while palms come to production (Nchanji et al., 2016). Coconut palm has particular appeal as an intercrop with cacao as it induces less moisture stress than traditional shade-tree partners (Osei-Bonsu et al., 2002). Intercropping of coconut palms can have economic and cultural as well as nutritional benefits with co-production of threatened rattan species widely-used for artisanal production of household items also contributing to local income (Sonwa et al., 2003). In addition to these economic and nutritional benefits, involving stakeholder

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**Fig. 1.** Opportunities for improving efficiency, productivity and inclusivity as part of circular economy and systems thinking applied to the palm crop agricultural cycle (see text for details).

partnerships at many levels to assess alternative crops and develop guidelines for these strategies could revolutionise large-scale agroforestry practices in Africa, with substantial implications for soil enhancement, biodiversity conservation and in promoting the sustainable development of agriculture (Brooker et al., 2014) (Fig. 2).

Furthermore, palm breeding programmes can be accelerated by the advent of rapid genetic transformation techniques using CRISPR systems (Ran et al., 2013). These offer the potential for developing more resilient varieties, including enhanced pest and disease resistance, stress tolerance and optimised phenology and productivity. Genes for drought and salt tolerance have been identified in other palms (e.g., Australian *Howea*, (Osborne et al., 2019)), and their orthologues in crop palms could be either replaced by those from *Howea* or their expression increased. With such developments in tandem with agronomic improvement of soils, there is an opportunity to grow palms on poorer soils currently neglected by agriculture, thereby also diminishing pressure for expansion into forested areas rich in biodiversity. The predicted and very substantial, decline in suitable palm-growing habitat can be mitigated by developing capacity and supporting such technologies in African institutions. This, in tandem with established local evaluation and selection, could deliver palms that can be productive in current and future marginal situations. This approach also has the potential to contribute to net carbon sequestration in palm plantations through use of degraded or marginal lands (Paterson and Lima, 2018).

To create an element of circularity in the palm economy, palm waste can be used for protein co-production. Palms can help supplement food and local incomes indirectly: palm trunks, which are regarded as agricultural waste, can be used for farming palm weevils (*Rhynchophorus* spp) (Fig. 1). Palm weevils are an excellent low-cost source of essential nutrients and are highly prized in the regional market (Anankware et al., 2015). Developing guidance for, and a demonstration of, small and medium scale commercial co-production of insect protein in tandem with improved cropping stock and practice creates a win-win synergy. In Ghana and Côte d'Ivoire, for example, palm weevils serve as a traditional meal in most rural societies but are not yet extensively farmed for consumption (Laar et al., 2017). Palm weevil farming would be a cost-effective co-enterprise in terms of supplies and labour and efficiently complements palm plantations for nuts (Dickie and Collins, 2019). The larvae of palm weevils reach harvest size within three to four months and can rapidly become a commercial co-product of primary palm farming. Using the soft apical portion of the crown (the palm yolk), a single palm trunk can help produce 1–4 kg of palm weevil larvae for animal or human consumption, worth 10 to 40 US dollars (e.g., see (Commander et al., 2019)). The bulk of the trunk

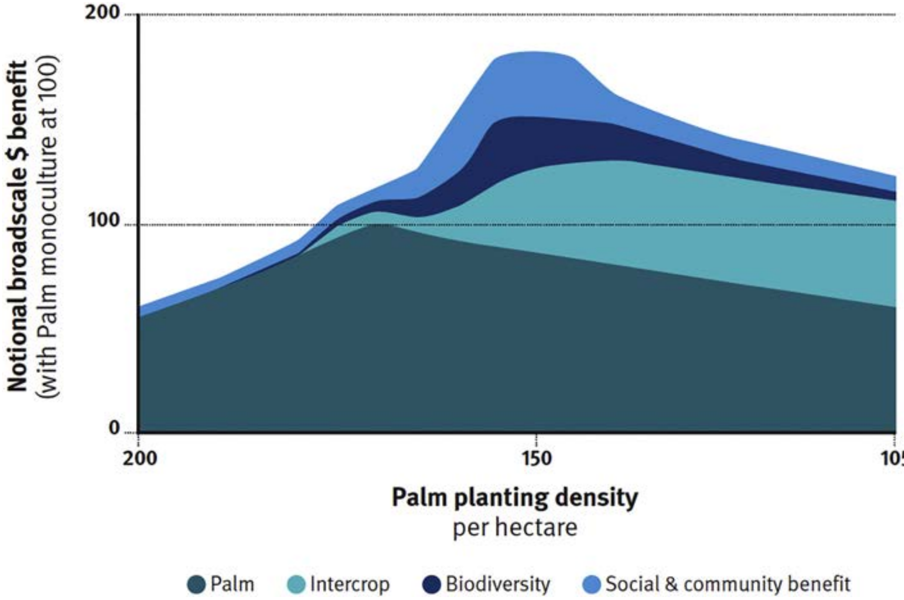


**Fig. 2.** Theoretical model for added values as a function of palm tree spacing within plantations (see text for details).

can also be used for palm wine (i.e., fermented sap), and once shredded, the trunk can be used for mushroom cultivation. In addition, the nutrient rich frass arising from weevil farming (i.e., insect waste), along with other palm waste, can be used to improve soils. Finally, the hollowed palm logs have further market value as ornamental containers. The decline in wild-caught insect protein in much of Africa has led to increased interest in community and commercial insect farming that can operate alongside other agricultural activities (Anankware et al., 2015). In southern Africa, commercial production of mopane worm is starting, and there is now substantial interest in palm weevil farming. Developing agricultural outreach programmes and the practical advice to promote this circular development is critical to increased uptake. Currently, though pilot ventures do exist, little advice, training or example is available to help scale this development (Amponsem, 2016).

Palm agriculture has a 'bad press', especially for the oil palms in South-East Asia. The 12 million hectares of Asian palm oil plantation, mostly in Indonesia and Malaysia, are responsible for substantial deforestation and threaten many species, including charismatic orangutans (Meijaard et al., 2018). In Africa, palm plantations are currently less controversial, although it is crucial to drive their development in the direction of sustainable agroforestry ecosystems. To mitigate the environmental impact of palm plantations, growing crop palms in areas currently occupied by less efficient crops and/or outside biodiverse tropical areas is a positive way forward. Redefining and recycling palm agricultural waste and using intercropping to add value to plantations bring other benefits (Figs. 1 and 2). New governance tools for conservation, such as certification programmes, exert international pressure to mitigate the worst environmental impacts. The IUCN Oil Palm task force was established in 2017 and aims to act as an authoritative advisory body to various stakeholders involved in the oil palm business (Meijaard et al., 2018). Their global analysis, involving both smallholder and agro-industrial oil palm stakeholders, has identified important safeguard measures to avoid the impacts of palm plantation expansion on biodiversity. Furthermore, recognising that large-scale oil palm plantations can have adverse effects on local communities is key to the future development and implementation of sustainability actions in the oil palm sector. Notwithstanding, legislations that favour the implementation of governance initiatives geared towards voluntary certification of palm plantations will contribute towards the livelihood and welfare of local communities. This will ensure local communities are incentivised for looking after these plantations and that their land rights are protected.

It is critical, and increasingly acknowledged as such, to integrate the local human dimension in such new economies, including promoting gender equity. For example, wild harvesting of palm weevils has long been a part of the female gathering culture in West Africa and increased use of pesticides along with land use change has substantially reduced this. There is a cultural knowledge and currently strong memory of this as a key nutritious food in African rural communities that can be leveraged to small-scale farming (Chia et al., 2019). The explicit inclusion of this to the palm agricultural cycle provides substantial economic and nutritional opportunity, while contributing to empowerment of vulnerable people and to gender equality.

We consider that a roadmap towards a sustainable palm future can be developed and implemented. A collaborative, multi-level and inclusive programme would create a real opportunity to improve both the reputation of palm farming in Africa by explicit inclusion of biodiversity and human benefits to this cropping cycle. This would contribute to economic and social gain and reduce environmental destruction while permitting enhanced crop productivity in several dimensions.

## Declaration of Competing Interest

None.

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