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Smart farming and artificial intelligence in East Africa: Addressing indigeneity, plants, and gender

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ABSTRACT

Precision agriculture, including the deployment of robotic farm workers, artificial intelligence (AI) driven equipment, and corresponding "smart" systems, is being enthusiastically lauded for improving crop yields, strengthening food security, generating economic growth, and combating poverty. Techno-optimism has captured the imagination of media, industry, and governments alike. Simultaneously, researchers in the computer science and machine learning spaces have begun cataloguing potential harms that arise from information technologies that are shaped by bias, discrimination, and Western hierarchies of power. While precision agriculture and smart farming technologies may provide some opportunities for East African smallholder women farmers, they may also emerge as a new—yet familiar—system of appropriation and control over their labor and knowledge. Concurrently, there is a need to address how such technologies continue to reinforce plants as mere objects to be optimized and managed, rather than "smart" beings with their own material forces and ways of knowing that shape our worlds. This article considers how precision agriculture and smart farming are potentially managing, surveilling, and optimizing both women farmers and plants in ways that reinforce hierarchies and disregard Indigenous ways of knowing and being. It models a decolonial mode of deliberation toward governing smart farming and related artificially intelligent technologies in more meaningful and inclusive ways.

Introduction

Robots are on their way to East African farms. The deployment of robotic farm workers, and corresponding "smart" systems, is being enthusiastically lauded as the clear solution for improving crop yields, strengthening food security, generating GDP growth, and combating poverty. For precision agriculture (PA), and its fellow traveler artificial intelligence (AI), these benefits are often highlighted as data collection, amplification, and utilization to streamline processes and increase efficiency. This language of techno-optimism has captured the imagination of media, industry, and governments alike. It portrays what Bronson [9] describes as the "immaculate conception" of data, in which data acquires agency (*i.e.* "data-driven") as the thing itself that improve agricultural outcomes. Globally, numerous intergovernmental organizations are actively promoting the potential of digitalized, data-driven agriculture. The Food and Agriculture Organization (FAO) of the United Nations, the World Bank, and the Organization of Economic Cooperation and Development (OECD) have all developed work programmes focused on the promises of precision agriculture and smart farming [23,24,70,111].

Recently, the East African agricultural sector has begun to leverage AI to increase agricultural output and mitigate the effects of climate change. These transformations may offer some significant advantages over past practices: the AI applications that have been introduced in the East African sector primarily provide information, connect farmers to marketplaces, and help identify crop disease. UjuziKilimo, for example, is an AI platform developed and launched in Kenya that provides agricultural data to smallholder farmers [100]. There are also AI applications that have been introduced into the Kenyan agricultural market that that allows smallholder farmers to access inputs, credit and markets: Tulaa, AGIN, and Apollo Agriculture ([3]; Apollo [5,56]). Similarly, ProjectFARM is an AI platform that decodes patterns in farmers' activities and generates insights based on a combination of data gathered [11]. At the forefront of these efforts has been the work of women

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software developers such as Nazirini Siraji from Mbale Uganda who created the "Farmers Companion App" using Google's TensorFlow, Google's open-source machine learning platform, to prevent the spread of Fall Armyworm from damaging crops [33]. At the same time, men continue to make up the majority of the labor force within AI projects and companies originating in countries across Africa [13], which results in significant gender disparities with implications for emerging AI-based agriculture technologies.

Used responsibly, precision agriculture and smart farming could potentially ameliorate some of the longstanding challenges facing East African agriculture; yet, we argue some caution is warranted. When scrutinized critically, precision agriculture and smart farming emerge as important sites for understanding potential impacts of AI technologies and developing ways of governing them towards social justice. Such perspectives are an essential complement to economic, technical, and environmental analyses, if field robotics are to achieve their full potential. Informed by critical race theory, researchers in the computer science and machine learning spaces have begun cataloguing potential harms that arise from information technologies that are shaped by bias, discrimination, and Western hierarchies of power. Notably, researchers Joy Buolamwini and Timnit Gebru, with their landmark "Gender Shades" project, demonstrated that facial recognition software more reliably recognizes lighter skinned faces than darker skinned faces, masculine faces more than feminine faces, while recognizing women with darker skin the least [10]. Safiya Umoja Noble has brought attention to "algorithms of oppression"—the racist and misogynistic impacts of seemingly neutral search engine algorithms [68]. Ruha Benjamin has described how datafication and discriminatory design entrenches structural barriers that perpetuate inequality for historically marginalized individuals, thereby resulting in a "New Jim Code" [6]. Taken together, such critiques call for increased attention on the types of data used, the designers making decisions for using them, and the need for more social justice approaches that attend to social hierarchies of inequality. Such critiques are relevant to the lived realities of potential African users, who will undoubtedly exhibit characteristics and cultural tendencies unanticipated by the prototypical Silicon Valley programmer [113].

Even such critical perspectives, however, tend to focus on Western values and conceptions. As AI trades chiefly in the business of prediction, what algorithmic systems might predict is necessarily mediated by cultural expectations and norms. Cultural aspects of knowledge can vary significantly throughout the world; absent careful attention, design choices can import cultural norms or expectations from different social milieus. Interviews in the documentary *Coded Bias* emphasize how AI can easily entrench the norms of its designers when transposed to a new cultural setting—with some scholars explicitly arguing for Western democratic ideals as a preferred normative export [43]. Technology law scholars have also produced valuable insights on the impact of normativity on the creation of coded spaces [49,79], and the extent to which law is shapes and is shaped by local language and culture [95]. Al-based technologies, including precision agriculture and associated smart farming technologies, will have differing impacts in the context of the African continent.

This article is concerned that while precision agriculture and smart farming technologies may provide some opportunities for East African smallholder women farmers, they may also emerge as a new-yet familiar-system of appropriation and control over their labor and knowledge. Such control evokes legacies of colonial extraction and exploitation. Concurrently, there is a need to address how such technologies continue to reinforce plants as mere objects to be optimized and managed, rather than "smart" beings with their own material forces and ways of knowing that shape our worlds.

Some might disagree with the premise of gazing beyond capitalist logics framing agriculture as business and accepting agricultural innovation as imperative if not inevitable. Certainly, the predominant worldview informing smart farming discourse to date understands plants as mere commodities. Those sharing such a worldview may, perhaps subconsciously or inadvertently, deemphasize the value of local, Indigenous, and women's knowledge. It is fair to ask why a more critical analysis can be valuable.

The discussion in this article is not meant to argue for plants as legal subjects *per se* or a moral obligation to avoid commodification. Yet, given the way data is vitalized through discourse, as though ones and zeros are alive, and imbued with intelligence, should it be so shocking to say that plants may too be "smart" in many senses of the word? A critical framework is presented as a thought experiment to challenge human exceptionalism within the law. Governing AI through an exceptionalist lens is too limited: it prevents a more radical vision for governing AI towards social justice. Robust visions for AI governance must consider how precision agriculture and smart farming are potentially managing, surveilling, and optimizing both women farmers and plants in ways that reinforce hierarchies of knowing and being, diminishing the legitimacy of Indigenous orders and undermining Indigenous data sovereignty. This article therefore considers an approach to the governing of AI that begins to account for Indigeneity, plants, and gender in a more inclusive and robust manner.

In this way, we model a decolonial mode of deliberation towards governing smart farming technologies in more meaningful and inclusive ways. Expanding upon previous contributions on smart farming [50] and the colonial aspects of AI technology (Foster et al., 2020), this article begins by distinguishing related practices of precision agriculture and smart farming. Focusing on small-scale women farmers in East Africa, it then attends to dominant narratives of techno-optimism, ahistoricism, and human exceptionalism that frame precision agriculture and smart farming technologies. It then suggests three lines of inquiry for developing more robust ways of governing AI that take gendered and vegetal histories, lived realities and materialities, and ways of knowing into account. It also pre-emptively responds to critics who might argue against the article's central contentions, clarifying the tenor of the objections levied. Finally, it concludes with how attention to gendered relations and vegetal beings can inform debates over open data and Indigenous peoples' data sovereignty.

The outcome of this analysis is a framework that can actually promote, rather than hinder, the development and deployment of precision agricultural technologies. A more inclusive governance framework focused on equitable benefit-sharing for all can help to avoid, or at least reduce, some of the conflicts seen around other technological revolutions, most notably genetically modified organisms (GMOs). Recognizing the technology is a potentially valuable component of food security, environmental sustainability, economic stability, and more, our aim is to make the rollout of these technologies as positive as possible. Simply ignoring gender inequalities or excluding those with non-Western worldviews will exacerbate not ameliorate conflict.

Precision agriculture, smart farming, and narratives of techno-optimism

Precision agriculture and smart farming are not single technologies, but data-driven systems devoted to improving the profitability and sustainability of agriculture by using computational and information technologies. Conceptually, they are connected to rapid developments in big data, the Internet of Things (IoT), and cloud computing. They refer to the mechanization of agriculture and datafication of farm management through surveillance and monitoring technologies, which often include sensors for tracking soil and livestock, and satellites, planes, and drones for overhead sensing of plants and crops. The term "precision agriculture" emerged in the 1990s as farmers began to use precise geolocation data and eventually complex geospatial data (*e.g.*, Geographic Information System, GIS) to manage crop yields [83]. More recently, the term "smart farming" refers to more advanced precision agriculture technologies such as "smart" sensors that provide farmers with real-time data to share with others via big data databases for

making even "smarter" decisions for optimizing crop yields [83].

Rather than a distinct break from conventional farming, precision agriculture extends an intensification of farming over time [55]. Although precision agriculture ushers in new step-by-step rules and computational processes for making data-driven decisions for farming, it draws upon and reinforces the systems of standardization brought about by the Green Revolution's shift from small-scale to large-scale industrial farming [18]. Issues ranging from Monsanto's genetic modification of seeds to the World Trade Organization's harmonization of intellectual property laws have harmed small-scale farmers, especially women farmers. Development scholars have offered valuable insights into the impacts of these harms, including contending with monocrops that are less resistant to changing environmental conditions and with legal regimes that prevent them from owning facets of the very seeds and farming technologies they need for their livelihoods [8,87,103]. With the advent of algorithmic-based software, sensors, and farming equipment that are subject to intellectual property protections, women farmers have even fewer meaningful opportunities to own and protect their knowledge, heritage, and practices related to farming than ever before. As a set of practices that seeks to manage and optimize plants for global circuits of distribution and profit, precision agriculture and smart farming also extend logics of reductionism that reinforce plant beings as inert raw material.

More than a set of technologies, precision agriculture and smart farming are a knowledge system that values algorithmic decision-making over women farmers' ways of knowing, while foreclosing consideration of plants as "smart" beings on their own terms. They are embedded within what Ted Striphas [91] calls a rising "algorithmic culture," wherein human expression and its accompanying work of culture—"sorting, classifying, and hierarchizing of people, places, objects, and ideas"—is delegated to logics of big data and large-scale computational processes. In the techno-imaginaries of PA, farmers are expected to cede their authority to machines and algorithms that become the centers of command and control in decision-making [55]. As a set of rules and mathematical procedures, algorithms (and their designers, owners, and users) are given authority and value as arbiters of truth and knowledge about the world. While Eastern African women farmers hold significant knowledge about local soils, plants, and animals, the ethos of algorithmic culture bestows greater value upon precision agriculture and smart farming technologies as producing more accurate, correct, and precise knowledge of farming. Plants are increasingly becoming recognized as knowing beings with intelligence [52] and awareness [12] that inspire AI innovation with their distributed networks. Normative framings of precision agriculture and smart farming value data and machine-learning in ways that make it even more difficult to consider how plants might help us imagine the governing of precision agriculture and smart farming differently. What is at stake is a further devaluing of plants as mere commodities and of local, Indigenous, and women's knowledge—and the entrenchment of hierarchies of knowledge production. Strategies for the governing of AI-based technologies, including PA, must contend with and work to mitigate the impact of such hierarchizing for East African small-scale women farmers, plants, and their integral relations to one another.

Narratives of techno-optimism accompany these proposed solutions of precision agriculture and smart farming. For instance, the World Bank's "knowledge and learning platform" on "data-driven digital agriculture" is described as a "one-stop-shop to share knowledge, analytics, innovations, tools, and best practices" [111]. The OECD's complementary work on "digital opportunities for better agricultural practices" has expanded to integrate farmers' perspectives in data governance in the digital transformation of agriculture [70]. As a global leader in food and agriculture policy and a UN agency committed to achieving the Sustainable Development Goals such as eliminating global hunger (SDG2) and achieving gender equality (SDG5), the FAO also has an active programme of activities around digital agriculture, including an "e-agriculture" strategy and a "digital services portfolio" [23,24]. In describing precision agriculture and smart farming through a language of optimism as "better" agricultural practices, these global UN programs contribute to understandings of knowledge based on algorithmic data as more worthy than Indigenous peoples' and local knowledge. Narratives of techno-optimism bolster precision agriculture and smart farming as more "modern" and therefore more valuable, while reinforcing hierarchies of knowledge production that have historically devalued the knowledge and labor of women and Indigenous peoples' as mere intuition and unskilled.

Associated with narratives of techno-optimism is a language of ahistoricism, meaning a lack of attention to history and historical context, especially how AI is embedded within legacies of the colonization of Africa. The framing of precision agriculture and smart farming as better and more valuable is also about what stories are not told. The characterization of precision agriculture and smart farming technologies as more precise, accurate, and objective depends upon delimiting them from conventional (read: traditional) farming practices and ways of knowing. Discussions of precision agriculture and smart farming are devoid of attention to the role of farming in the colonization of the African continent and the subjugation of both African peoples and plants. This ahistorical framing not only bolsters precision agriculture and smart farming as novel technologies, but also obscures an understanding of how these technologies continue to reinforce colonial pasts and associated logics of extraction.

Like the colonial extraction of the continent's natural resources, the taking of Indigenous and African peoples' knowledge as data threatens their communities. It also enables Global North countries to maintain asymmetrical relations of power by continually repackaging and reselling technological solutions, and by propagating out-of-context solutions that further a dependency on Global North resources [1]. This framing results in the application of precision agriculture and smart farming without attention to the histories of African women in agriculture, where a digital gender gap continues to widen, despite women making up the majority of small-hold farmers [81]. Often, women are considered as beneficiaries rather than full partners or co-contributors to AI technologies; this framing risks reproducing colonial practices of alienating African people from production [67,81]. It also leaves colonial histories of botany unexamined and how the taking of plants and other natural resources contributed to the colonialization of African peoples, lands, and heritage [38].

The ahistorical framing of precision agriculture and smart farming contributes to the naturalization of algorithmic technologies as inherently delimited from colonial pasts. For instance, metaphors likening data to a new form of oil evoke colonial exploitation of lands in the age of empires. Luke Stark and Anna Hoffman note that the describing digital data as an element of the "natural world" allows power-holders to occlude the role that humans play in data-generating activities [89]. Such narratives are consistent with the justifications used for imperialistic practices and colonization. As Kate Crawford writes:

The expression "data as oil" became commonplace and although it suggested a picture of data as a crude material for extraction, it was rarely used to emphasize the costs of the oil and mining industries: indentured labor, geopolitical conflicts, depletion of resources, and consequences stretching beyond human timescales ([15]*, p. 113).*

A lack of attention to colonial histories hinders a broader understanding of how precision agriculture and smart farming technologies deploy "data" in ways that reinforce colonial logics of extraction. It also obscures attention to how precision agriculture and smart farming tools deployed by women across the African continent are primarily designed and controlled by Western developers using African peoples' knowledge packaged as data. This replicates the Eurocentrism and power asymmetry that are key components of colonization [1,7] by associating the making of innovation with the West and the taking of raw materials with Africa. Examples include Plant Village's Nuru, an app used to diagnose multiple diseases in staple African crops including maize, cassava, and potatoes. While Nuru is designed for African farmers, its lead members

(founders, engineers, and designers) are primarily of European descent, with African team members dubbed the "dream team" [76]. This trend is similarly present with "Farmer Charlie," an app claiming to bring connectivity to farmers at a low cost, including information on farmers' fields and market opportunities [25]. Other such projects include "Wefarm," a communications platform for farmers in Kenya [107]. A more socially just vision for the design, implementation, and governing of precision agriculture and smart farming requires attention to how these technologies are related to colonial pasts and legacies.

Conversely, there is a small but growing number of African women disrupting this trend. As mentioned, for example, Nazirini Siraji from Mbale Uganda created the "Farmers Companion App" using Google's TensorFlow, Google's open-source machine learning platform. It identifies when crops such as corn have Fall Armyworm (FAW) including how likely it is to spread as well as advises farmers on treatments to stop the spread [33]. Organizations like She Code Africa are also slowly changing the landscape by encouraging African women to occupy the tech space through mentorship and training programs [86]. While these efforts challenge gendered hierarchies of labor and knowledge production by enabling and positioning African women with authority as producers of Al-based technology, they are limited by their attachment to dominant AI-technology practices and protocols that are not directed towards challenging gendered hierarchies of labor and knowledge or considering non-human plants as more than raw material. How might the Farmers Companion App provide farmers new tools to fight FAW and enable East African women small-holder farmers? How might it be designed to promote food justice and gender equality? At the same time, how might the Farmer's Companion App challenge human exceptionalism? How can attending to plants enable a more radical vision of smart farming that emphasizes care and responsibility for women and plants, and the more-than-human worlds they depend upon?

Ultimately, the dominant narrative of techno-optimism and its language of ahistoricism demands reconceptualization. Barring its disruption, dominance will take the form of data science, claiming impartiality through the binary output of ones and zeroes, making narrative accounts of African women small-holder farmers less likely and, correspondingly, less valued. Hildebrandt [39] refers to overemphasis on digitized accounts as producing an "unwarranted aura of objectivity" (2018). As algorithmic activities increasingly obscure the background machinations that generate digital outputs, identifying sources or validity of information becomes newly difficult. Set against continuing colonial legacies, this underscores the importance of intervention at the information curation stage by attending to gendered and vegetal histories, lived realities and materialities, and ways of knowing.

Gendered and vegetal colonial histories

A more socially just approach to the governing of precision agriculture and smart farming technologies must take colonial histories into account. Failing to recognize the colonial influence of technology threatens to destabilize cultural ways of knowing. Perceived supremacy of colonial legal orders has generated a lasting legacy of erasure for Indigenous legal orders and ways of being. The doctrine of *terra nullius* wrought particular harm to Indigenous cultures worldwide, as colonial powers declared newly "discovered" lands as empty and, correspondingly, empty of any pre-existing legal orders. These legacies of ahistoricism have had catastrophic consequences, discounting traditional forms of knowledge and imposing Western colonial logics [58]. Just as *terra nullius* doctrines nullified Indigenous legal orders to create space for a new, exploitative legality, data-generating activities are presented as a resource awaiting extraction. To better encapsulate the realities facing East African women farmers, bringing colonial histories of agriculture to the forefront works to challenge the colonial logic of extraction that might otherwise be embedded in precision agriculture and AI, and open up possibilities for governing and building better smart farming technologies.

Land is of vital importance in East Africa. It offers identity, status, and economic security. Many of the tribal creation myths and status symbols contain elements from and of the land. For example, the creation myth of the Gikuyu tribe in Kenya states that after creating the first man, Gikuyu, God (Ngai) appeared to Gikuyu and allotted him the land at the south-west of Mount Kenya: a fertile area in central Kenya that is still primarily occupied by the tribe to this day [32]. Africa's relationship with land may be viewed in pre- and post-colonial terms: a precolonial context of land abundance and relative labor scarcity to the late colonial and postcolonial situation of rising populations and growing pressure on land.

In the pre-colonial era, women's agricultural activities varied across the continent, dictated by tribal practices and location. The women in agro-pastoral societies of the savannah played a bigger part in farm labor than the women in the forest zones; while in the tropical forest zones heavy clearing work was usually a job for men, the tasks of planting and weeding were for women, and harvesting for both [36]. In some East African regions, women played significant roles in cash crop farming—cotton growing in Uganda, for example—while in other regions women were specifically relegated to subsistence farming [28]. The advent of colonialism led to a restructuring of existing systems and cultural identities across the continent. Colonialists enacted laws and policies to mimic their countries of origin. Colonial land policy overwhelmingly resulted in the disenfranchisement of Indigenous peoples, inequality in land ownership and use, resentment by Africans, landlessness, squatting, land degradation and poverty that continues to plague the continent [14,16,40,48,93]. European and Western standards also tended toward the exclusion of women from public life and commercial activity. They introduced a gendered dichotomy in the division of agricultural labor: subsistence farming, stereotyped as women's domain and cash crop farming, stereotyped as men's domain [108]. While Ugandan women typically cultivated cotton, British colonial authorities taught only men how to operate new technologies for cotton growing, effectively transferring economic ownership of the crop from women to men [28]. These policies exacerbated existing gender disparities and introduced inequalities where none had previously existed, *e.g.*, in tribes with strong matrilineal heritage. Colonial land policies often persisted even after nations attained independence leading to ongoing land conflicts and gender disparities.

In bringing these colonial histories to the forefront, an intersectional, multi-species approach is needed; one that can attend not only to relations of gender, race, indigeneity, class, and colonial histories, but also to the very soil, plants, and animals being monitored by PA. It is not enough to address colonial legacies of Eurocentrism and gendered white supremacy; attention must be directed towards challenging historicizing in ways that challenges human exceptionalism. An ethics of care and responsibility must extend to humans and nonhumans alike, attending to how precision agriculture impacts farmers and plants. How might addressing colonial histories related to plants provide robust insights for the governing of AI and PA?

Attention to the philosophical and scientific categorizations of plant life shows how its debasement is central to regimes of patriarchal white supremacy and the hierarchical ordering of society that have contributed to the subordination of East African women farmers. Through the writing of Aristotle, plants emerge as the lowest order of life given what is considered to be their lack of movement and uncontrolled growth. Animals are given slightly more consideration, understanding them as having a propensity for movement, sensation, and desiring appetite. Aristotle bestows supremacy though to certain humans (read: white and male) for attachments to language, reason, and higher concepts of science and knowledge production. Entrenching these hierarchies further, eighteenth century Swedish botanist Carl Linnaeus developed taxonomies that simultaneously classified plants as mere nature, and African peoples as closer to animals [34]. Linnean taxonomies, Londa Schiebinger [85] demonstrates, drew upon and naturalized Victorian era categories of normative gender and heterosexuality by describing plants

as entering into marriages where male assigned stamens and female assigned pistils came together to reproduce. In the case of the *Hoodia gordonii* succulent plant, Laura Foster [27] demonstrates how colonial botanist Francis Mason extracted Hoodia plants from Kalahari Desert lands designated through colonial legal doctrines of *terra nullius* as "empty" lands, while writing of his encounters with San peoples whom he referred to as primitive people of the Bush, thus reinscribing them as closer to plants and less than human. Asserting these linkages demonstrates how the ordering and classification of plant life is not only embedded within these gendered and racialized hierarchies and histories of colonial science, but actively a part of them. How then might the subjection of plants and plant ways of knowing be integral to precision agriculture and smart farming technologies that impact East African women small-holder farmers?

Gendered lived realities and vegetal materialities

These colonial histories continue through legacies of inequality that continue to impact East African women small-holder farmers and plant beings. To challenge these residues of colonial pasts and envision more socially just ways of governing precision agriculture and smart farming, it becomes imperative to address the lived realities of East African women's lives and consider how the materialities of plants offer new ways of thinking about such technologies.

Agriculture remains the economic backbone of the African continent. Approximately 23 % of sub-Saharan Africa's GDP comes from agriculture, comprised of 60 % smallholder farmers [30]. These trends hold true across the East African region. In Kenya, approximately 80 % of citizens engage in agricultural activities for their livelihood; on the whole, agriculture accounts for 43 % of the region's annual gross domestic product (GDP) [64,105]. Meanwhile, African women dominate the agricultural work force, making up between 60 and 80 % of the total agricultural labor force [66]. The trend toward the feminization of agriculture is fuelled by the rural to urban migration of men in search of paid employment in towns and cities [2]. But, they often lack control and obtain fewer proceeds [66]. Furthermore, they rarely own land; they often accessing land through a male relative, which leaves them in precarious economic positions [19]. They also lack access to farming inputs (*e.g.*, fertilizers, seeds, and farming implements) [22]. The adoption of AI-related farming technologies is likely to exacerbate these gendered inequalities.

In Kenya, women provide between 42 % and 65 % of the agricultural labor force [4,75]. A 2010 study found that division of farming labour was influenced by gender; while men are often involved in heavier farming duties such as ploughing, female farmers are the primary labor in all other processes in both subsistence and cash crop farming (National Agriculture and Livestock Extension Policy [[63]P], 2010). Similarly, there is often gendered division in the types of crops associated with male and female farmers, with cash and export crops regarded as men's crops and subsistence crops as women's crops [37] Cultural practices and fiscal constraints often bar women from growing higher value cash crops. For example, female farmers in Ghana acknowledge maize as a high income generating crop, but often refrain from growing it because they lack the capital to purchase the required inputs or hire someone to plough the field [37]. The gendered aspects of cropping in matriarchal societies differ significantly from those in patriarchal societies. In Tanzania, a study conducted on a matrilineal society residing in Tchenzema ward in the Western Uluguru mountain Morogoro found that there was no clear cut division of labor between gender in either cash or food crop production [59]. Instead, decisions on production and resource allocation were done jointly between spouses although decision on hire of labor was mostly done by men [59].

Despite their contributions to the agricultural sector, women still lag behind in securing land rights. Women in Kenya, predominantly those in rural areas, are more likely to be systematically excluded from family and patriarchal land ownership. Many women can access to land exclusively through male relatives; only 10.3 % of Kenyan women own land title deeds (Kenya Land [45,57,60]). A 2005 study found that widows in the country are 13 % more likely to experience land conflicts when their parcels are registered under the names of their deceased husbands than when titles are registered under their own names [112]. Additionally, women farmers in Kenya have little or no access to credit, usually stemming from a lack of collateral, such as land [44]. Because women farmers often do not own the land they work, their ability to control over proceeds of their own labor is correspondingly impacted. For example, in Kenya, payment for certain commodities such as coffee is awarded to the title deed owner of land rather than its cultivator; this means that women are unable to monetize their contributions in cultivating the crop [102]. In fact, women do more than two-thirds of the work involved in coffee farming in Kenya but hold fewer than 5 % of leadership roles in coffee cooperatives in the country [73].

When Indigenous peoples are dispossessed from their land by government or private entities in favor of more powerful interests (such as the flower growing industry in Kenya, or mining interests in Ethiopia, or oil exploration in Northern Kenya, or national parks in Uganda and Rwanda), women are usually further disenfranchised—often losing access to important agricultural productivity resources such as water [35]. Women tend to be disproportionately involved in those subsistence activities that can be more easily managed alongside household responsibilities, such as cultivating vegetables and taking care of homestead garden [35]. The effects of Green Revolution technologies had gender-differentiated effects. The measures deployed in the Green Revolution (high yield seedlings, chemical pesticides, irrigation technologies, etc.) increased the need for cash income, which often intensified women's work burden in small-holder farms, either by pushing them into agricultural wage work, or into doing more unpaid work to avoid the use of hired laborers (United [101]).

This may also prove to be the case for the farming technologies of the Fourth Industrial Revolution. There is concern that AI will widen rather than mitigate existing gender disparities. The needs, priorities, and realities of women in the region need to be recognized and adequately addressed in the design and application of smart farming application for them to benefit fully from their utilization. AI platforms that improve women's access to land and land rights, tenure of natural resources, access to justice, production inputs, financial information and services, farm labor would also help redress the gender disparities in the region's agricultural sector. AI to improve women's access to information on climate change would also be useful. Women farmers in the region have adopted measures that mitigate climate change effects faster than their male counterparts. In Kenya, the most rapid adoption of drought-resistant crops was among women whose husbands were away and not making the day-to-day decisions [31,99]. AI could make it easier for smallholder women farmers to coordinate and leverage their buying and selling power.

While strategies for the governing of precision agriculture must address the material conditions of farming in Kenya that exacerbate gender inequality, *e.g.*, generating limited returns and benefits for women's labor in tea production [104], they must also consider the material practices and activities of plants themselves. Attending to the materiality of plants offers pathways for farmers to develop practices of care that exceed capitalist logics of plants as mere resource for humans and re-conceptualize plants as important contributors to shared human and more-than-human worlds. It also demonstrates how plants defy EuroWestern hierarchical understandings of living beings that are highly racialized, gendered, and heteronormative. Drawing upon developments in plant science, critical plant studies scholars contend that plants complicate binary understandings of vegetality and animality given their highly developed capacities for sensing, perceiving, responding, communicating, and adapting [53,65] . Growing across the Kenyan Highlands, for example, tea plants change habitats in search of higher elevations and cooler mountain air for more mineral rich soils in which to grow, preferring deep-well drained red volcanic soil [42]. They

shelter alongside taller plants such as *Hakea saligna*, and *Grevillea robusta* to protect their delicate leaves and white buds from harsh winds, while depending upon the same currents of air to help scatter their seeds. When rain is plentiful, their root and stem systems swell and become moist, storing up water to grow in drought conditions and provide nectar to the honeybee and shelter to small birds. Plants are active and lively life beings that shape human worlds, rather than mere commodities to be precisely monitored and surveilled. As legal regimes of intellectual property [84] and colonial agriculture policy [92] seek to govern plants and agricultural production, plants act in ways that interrupt and impede legal forces that seek to contain and control within capitalist logics [27]. The governing of precision agriculture through a multi-species ethics of care and responsibility should attend and respond to the material conditions of both women farmers and plants.

Gendered and vegetal ways of knowing

Framing precision agriculture and smart farming through narratives of ownership contributes to understanding Indigenous peoples' and women's agricultural knowledge as open data free for taking and privatizing. Smart farming companies advertise and promote their technologies as innovative in their use of open agricultural data, thus contributing to dominant norms of open access, open science, and open society that undergird notions of scientific and technological progress [54]. These arguments are fueled on the backdrop of the convergence of interrelated and often overlapping concepts around smart farming or precision agriculture and associated dynamics of ownership and control of data. They represent a critical layer in the progressive historical pattern of devaluation of the contributions of Indigenous peoples, especially women farmers to agricultural innovation and food security [78]. As indicated, the adjectivization of farming or agriculture with 'smart', 'precision' and associated qualifiers that emphasize innovation and the increasing role of data under the all-encompassing artificial intelligence phenomena are impliedly in juxtaposition to conventional farming practices, most especially informal and traditional knowledge-driven practices, which are propelled largely in Africa by women farmers.

Even though proponents of smart farming may not be deliberate or are at best insensitive to them, the nuances and power imbalance through which smart farming is currently promoted tends to build on colonial assumptions, 'othering', and devaluing of epistemic alterity [17]. As a language, concept and practice, smart farming and its synergy with open and big data reflect a new and burgeoning agricultural industrial complex that reinforces colonial and neoliberal structures with greater potential for further disenfranchisement of Indigenous peoples and women farmers to a scale beyond previous experiences. At the same time, precision agriculture and smart farming technologies may offer opportunities for Indigenous peoples and women farmers to generate alternative practices of these technologies that more meaningfully benefit them and enable their own efforts at self-determination and control over their knowledge and heritage. A more social justice oriented approach to the design, implementation, and governing of AI must place East African women small-holder farmers' ways of knowing at the forefront of visions for precision agriculture and smart farming.

East African women have developed expert knowledge of land, plants, and soil through generations of small-holder farming. Given gender roles that structure women as the main providers of food for their families, they are largely responsible for food production that benefits local consumption of their household and local communities ([106], p. 219). This means they are expert knowers of plants such as legumes and vegetables, and other subsistence crops [20]. Women farmers in Maragoli, Western Kenya have developed expertise regarding the planting of seeds, harvesting of crops, and caring for the soil ([102], p. 120). Women farmers in Nyeri and Kakamega, Kenya are also expert produces of maize crops, but differ from male-managed farms in their less frequent use of technologies such as hybrid maize, chemical fertilizers, pesticides, hoe, oxen plough, and tractor plough [106]. At the same time, a survey of farmers (59% of respondents were women) in the Lake Victoria region of Uganda found that the farmers primary utilized indigenous knowledge of botanical pesticides and other natural methods to control pests and improve crop yield [61]. Farmers in southern Uganda, including women, who are reliant on rain-fed agriculture for food supplies and income use informal and traditional knowledge systems to anticipate interannual variability in precipitation to adapt their growing practices to weather and climate change [74]. These ways of knowing and expertise become important for understanding and addressing the impact of precision agriculture and smart farming technologies on East African women small-holder farmers.

Alternative possibilities for precision agriculture and smart farming must recognize and value multiple ways of knowing and modes of sensing of both African women and plants. Examining gendered aspects of agriculture provides understandings into men's and women's different practices and decision-making related to agricultural production and the adoption of relevant technologies, while bringing value to women's expertise and ways of knowing about plants (Forum for Agricultural Research in Africa [26,82]). At the same time, thinking with and alongside plants challenges conventional understandings of nature as mere raw material in order to "cultivate new modes of embodiment, attention, and imagination, and new ways of telling stories about lands and bodies." ([62], p. 78). In heralding AI-based sensors as telling more accurate and true stories about plants and crops, precision agriculture implies that humans and plants tell less precise stories. Plants and trees are remarkable sensors of more-than-human-worlds, responding in distributed and networked ways to expansive interconnected systems of soils, microbes, insects, bugs, trees, water, wind, and light. They are active participant-observers with their stems, limbs, and bark recording changing ecological landscapes overtime ([62], p. 79) and botanical witnesses to colonial and settler-colonial violence [21]. Plants provide lessons on how to care about and for multi-species worlds of humans, plants, and animals that feed on their bodies, are sustained by them, and contribute to their ruin [62]. They are teachers, holders of knowledge, and guides to understanding more-then-human worlds [46] with unique modes of communication, articulation, and language all their own [29]. How might attention to plants destabilize algorithmic culture and its hierarchical ordering of algorithms as ultimate producers of knowledge? How might it offer more radical possibilities for governing AI through an intersectional, multi-species ethics of care and responsibility that responds to both the gendered inequalities and the destruction of plants?

Some groups of people, including farmers, data scientists, and government officials may argue that these questions are of little value, or that attention to local, Indigenous, and women's knowledge has no benefit for their work related to precision agriculture. Data scientists are committed to developing AI-based technologies to support farmers who are under pressure to grow increasingly standardized and uniform crop varieties to meet the demands of commercial food suppliers. Government officials are focused on enabling and regulating the use of AI-technologies to assist the agricultural industry and grow their economies. They also espouse the benefits of precision agriculture technologies for mitigating the effects of climate change by helping farmers to use less pesticides, promote soil health, and save water. Indigenous peoples and women small-scale farmers have developed valuable expertise over multiple generations on how to grow crops with an efficiency that is less harmful to the environment. Yet, the legacies of Western thought and the residues of colonization continue to characterize their knowledge as backward and traditional, thus bolstering the authority of data scientists, farmers, and government officials as producers of more rational and reasoned expertise related to precision agriculture. While some data scientists, farmers, and government officials may claim to value local, Indigenous, and women's knowledge they are often considered mere data providers, and they are rarely given decision-making authority or control over the means of agricultural and technological production and/or policy-making. This article contends

that those who develop, use, and govern precision agriculture technologies could benefit greatly from learning from and truly valuing the insights of Indigenous peoples and women small-scale farmers as expert growers and policy-makers.

Farmers, data scientists, and government officials may also argue that they do indeed value plants. Farmers have developed knowledge of growing plants over multiple generations and care deeply about the very plants and fruits they grow. Data scientists and government officials are working to build and provide AI-based technologies that ultimately are about making sure farmers can grow healthy and abundant plants. Processes of colonization and their attendant Western logics of human exceptionalism however have relegated plants as mere objects, rather than beings with their own ways of "knowing" and being in the world that could teach us something about how best to grow, nourish, and care for both humans, plants, and lands alike. This article begins to ask how we might think differently and produce better precision agriculture technologies that learn from plants as intelligent beings with strategies for growing that rely less on practices of standardardization and monocultures, which leave plants more vulnerable to climate change.

At first glance, taking a nuanced approach to the knowledge dynamics presented by gendered relations and vegetal beings might also appear to be at odds with more traditional views on agriculture as a business. One might imagine opposing this critical perspective through the lens of strict capitalist logics, driven solely by financial incentives to improve crop yields or seeding schedules through data-driven solutions. Yet, other, more charitable opposing views can also be conceptualized. For example, similar debates have taken place in the context of genetically modified organisms (GMOs), where advocates for using the technology argue the specific advantages of GMOs outweigh the potential detractors. Examples include the widespread proliferation of drought resistant maize in South Africa, which exceeds 80% of all maize crops planted [97]; as well as the 20-year development effort towards so-called "Golden Rice," which is rice enhanced with Vitamin A intended to prevent blindness and death in local human populations [90]. In such situations, focusing on human welfare can coincide with the capitalist incentives typically pursued through large, international agribusiness efforts.

Yet even these GMO success stories are hampered by neglecting the contributions made by the key groups identified: women and Indigenous peoples. Traditional African farming approaches are often led by women, who make key decisions about what crops will be planted to feed their families, while men might be more involved with crops intended to generate income [97]. In the GMO context, farming advancements are often associated with patents granting monopoly ownership to external entities, which tend to consider Indigenous knowledge as an aspect of the "public domain," thereby preventing the communities that collaboratively built local knowledge over generations from acquiring an ownership stake [69]. Similarly, the Human Genome Diversity Project, dedicated to mapping the human genome, heard vocal criticism from Indigenous populations and advocacy groups, who observed the project's focus as self-serving—and ignorant of the impact of colonialism on politics and history (Jenny [41]). In each of these scenarios, a more collaborative approach from the outset could prevent problems from accruing later, when efforts are revealed to have unfairly siloed complementary concerns. Combining the insights from the critical studies of big data and AI with the business of agriculture offers an opportunity to reconsider how issues around food studies and agribusiness are framed, without necessarily taking a normative stance [9].

Conclusion

Attending to gendered and vegetal histories, lived realities and materialities, and ways of knowing provides new ways of thinking about and building more meaningful precision agriculture and smart farming futures for East African small-holder farmers and plant beings. By way of conclusion, this section gestures to how these inquiries may inform debates over establishing guiding principles for the governing of AI and associated big data.

The centrality of data in smart agriculture and the imperative for data to be free, open and accessible under a global system of networked databases is now an animating logic for open science policy [47,109]. Evidently, the interest in data which has been analogized, albeit less accurately, to the new oil [96] is not limited to agriculture. It is now a catalyst for broader multidisciplinary science policy conversation. That interest is rooted in a dominant epistemic form and colonial privileging of western science and its conventions. In the agricultural sector, the logic of smart farming or precision agriculture and artificial intelligence is proselytized by a complex cacophony of actors often designated as agricultural technology providers (ATPs) and data intermediaries and, indeed, smart farming companies [77,94,110], whose relationships with Indigenous peoples and women farmers are fundamentally fraught.

Without delving into the dynamic of those relationships, ATPs and data intermediaries as adjuncts of open science and open data interests subscribe to the pun of F.A.I.R.(ness) as the guiding principles of scientific data management [109]. It reflects four cardinal essences to the effect that data needs to be findable, accessible, interoperable, and reusable. All the elements of F.A.I.R. leap out as misnomers in application to alternative knowledge systems outside the western scientific framework [72,80]. Neither knowledge production nor the organizing framework for sharing of knowledge among traditional knowledge holders in agricultural and other realms fits neatly under F.A.I.R [72]. What is clear is that under F.A.I.R. and its sponsoring epistemic and power structures, Indigenous knowledge holders, especially women farmers, are pressured for co-optation into a new agricultural landscape. In this landscape, Indigenous knowledge holders are at risk of being characterized as mere data providers, thus situating them within a clearly predatory or exploitative context wherein their interests are deliberately unaccounted for. How best to situate the interests of Indigenous peoples, traditional knowledge holders and others in the realm of epistemic alterity at the increasingly complex convergences of artificial intelligence and digital policy remains a lingering conundrum [51] that naturally dovetails with data management and data governance. How to take plants into consideration on their own terms and generate data governance that cares and is responsible to plant beings is completely left unaddressed.

Associating F.A.I.R. principles with open data, open science and their overall nesting in the ideology of openness for ease of R&D innovation does not presuppose that openness is necessarily inclusive [88]. In the context of Indigenous knowledge holders and African women farmers, the contrary is conjecturable. First, F.A.I.R. is meant to facilitate access to the use of data, most especially in the globalized and networked contexts for big data. It is not meant to foreclose proprietary or exclusionary use of freely obtained data under appropriate circumstances. This raises concern that African women's expertise of local plants and crops will be appropriated as data for others to freely access and profit from with no benefit to African women, and certainly no claims to ownership to their data. The emphasis on access to data about plants also supplants alternative attention to care for plants, and further classifies them as inert raw material to be used rather than another entity to be responsible to.

Second, the ability to access and use data and other sophisticated agricultural information is a function of multiple factors, including but not limited to education, digital literacy, technological and infrastructural competence and resources [98]. In all of these and many considerations, Indigenous knowledge holders, especially African women farmers have less of a chance to leverage data under the F.A.I.R. framework given the colonial histories and lived realities previously discussed. Access and use of plant and crop data also depend upon assumptions that they can ever truly be known. Engaging with plants reveals a complex distributed network of growth, signaling, communication, and change. Given the unpredictability of plants in relation to changing environments due to global climate change, data

about them should be considered as anything but certain. Third, F.A.I.R. hinges on an epistemic ideology based on valorization of data and information as premium agricultural asset. Among informal actors in African agriculture, including Indigenous agricultural knowledge holders and women farmers, the magnification of data as, arguably, the highest scale of value in agricultural knowledge production smacks of epistemic imposition not likely to fit within a holistic alternative episteme represented in Indigenous knowledge, and in plant worlds for that matter.

Owing to the narrow and, arguably, exclusive context for its elaboration, F.A.I.R. has elicited alternative and counterbalancing responses from Indigenous and local knowledge stakeholders. Those responses are relevant to the interface of smart or precision agriculture, artificial intelligence, and Indigenous knowledge holders, especially African women farmers. Indigenous people recognize that F.A.I.R.'s focus on big and open data does not account for whatever interest they may have on data as a pragmatic matter. Such interests are broadly articulated under Indigenous data sovereignty [71]. In response to F.A.I.R, scholars and activities engaged in efforts towards Indigenous data sovereignty have developed alternative principles of C.A.R.E., which stands for collective benefit, authority to control, and responsibility and ethics [80] These principles articulate Indigenous and local communities' expectation from data governance.

In bringing the pun full circle, Indigenous peoples and knowledge holders are in essence insisting that F.A.I.R. can only be fair if it is matched or complemented with C.A.R.E. In other words, there could be no fairness in data governance without an inclusive and deliberate attempt to care for the interests of Indigenous peoples and local communities. In this regard, seeking a meeting point, the Global Indigenous Data Alliance (GIDA) promote the hashtag "#BeFAIRandCARE". The increasing traction for Indigenous data sovereignty and the interfacing of F.A.I.R and C.A.R.E. principles of data governance are indicative of the persistent gaps that assail deployment of artificial intelligence and the valorization of (open) data and all the underlying logic of colonialism and power structure implicated in open science.

Attention to gendered and vegetal histories of colonialism, lived realities and materialities, and ways of knowing simultaneously aligns with, but could also strengthen efforts towards Indigenous data sovereignty further. How might data be deployed for collective benefit of Indigenous peoples, including East African women small-holder farmers and the plants they understand as ancestral kin? While Indigenous data sovereignty implies modes of "authority to control" that challenge capitalist logics of ownership, how does engagement with the uncertainty and unpredictability of plants question the very conception of control? Indigenous data sovereignty can be even further bolstered with attention to Indigenous women's expertise, organizing, and contributions to farming to ensure responsibility and care in the context of legacies of colonial gendered violence. While Indigenous data sovereignty implies responsibility for plant beings given Indigenous peoples' epistemologies of multi-species understandings, how might a more explicit engagement with plant beings strengthen C.A.R.E. principles further towards a vision of precision agriculture and smart farming that promotes mutual care for human, plant, and more-than-human worlds?

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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