The farm as digital factory

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Abstract

In this article, I develop the concept of the digital factory farm as a lens for understanding the shift from industrial to digital-industrial agriculture and its implications for managing and controlling agricultural labor. I argue, first, that digital technologies on farms deepen the real subsumption of labor and nature. Second, I contend that these technologies provide new avenues for interlinking capital's drive to reshape labor and nature. By analyzing the digital factory farm in South Africa's fruit industry, I uncover the mechanisms through which digital technologies serve this dual function. The farm as digital factory can stabilize highly globalized food commodity chains and might pose new challenges to farm workers' resistance.

Introduction

The 'farm as factory' has been a common metaphor to describe the process of industrialisation of agriculture, going back to McWilliams' (2000 [1939]) work on farm labour in California in the 1930s. Understanding the farm as a factory may seem counterintuitive at first. Industrial

factories are characterised by large buildings, assembly lines, time clocks, large machinery and mass production - not exactly the things we commonly associate with agricultural fields. However, as Deborah Fitzgerald (2003, 4) writes "*assembly lines have been developed in harvesting virtually all crops in which the product is stationary and the humans and machines move, and time clocks in the form of mileage recorders were installed on tractors and combines by 1921*". In the hundred years since, technological, and scientific innovations in agriculture and agricultural economics have made large-scale monoculture production, standardisation of agricultural products and processes, specialised machinery, reliance on managerial expertise and an emphasis on 'efficiency' commonplace in large-scale commercial agriculture. As in the factories of the Industrial Revolution, many of these processes were closely linked to attempts to standardise and routinise farm labour.

Almost 100 years after McWilliams writings and the beginning of industrial agriculture, we are seeing a renewed shift in the technologies and innovations used in agriculture. The "digital revolution in agriculture" is introducing a range of new technologies, such as big data analytics, automated equipment, and decision support software into the industrialised farming model. These technologies are designed to increase yields, provide greater control over plant growth cycles, optimise the use of inputs and track farm outputs as a way to increase farm profitability (Duncan et al 2021; Bronson 2019; Stock and Gardezi 2021). They are mainly developed and sold by large agri-tech companies, such as Bayer, Syngenta, or John Deere and generally support only a limited number of agricultural production techniques that follow the logic of large-scale monocultural and industrialised production (Carolan 2020a, Bronson 2022, Prause et al 2021). A key promise of digital technologies is the more precise management of the spatial and temporal heterogeneity in agriculture (Miles 2019), and thus greater control over nature. Precision farming relies on the provision of efficient and 'objective' data-based advice for example through farm

management platforms combined with farm machinery that allows for site-specific application of inputs (Clapp and Ruder 2020; Bronson 2019; Prause et al 2021). The digitalisation of agriculture thus promises to further optimise of the factory farming model, which relies on the standardisation of agricultural products and processes.

Optimising the factory farming model through digital technologies depends on the availability of big data. The collection of agricultural data is presented as a solution to address food insecurity, malnutrition, and the ecological crisis (Montenegro de Wit and Candfield 2023). However, rather than providing a path towards more (bio)diverse and sustainable farming practices and agricultural landscapes, these technologies are designed to increase the profitability of industrialised farms (Duncan et al 2021; Bronson 2019; Stock and Gardezi 2021). The data required for precision farming is produced by farmers using digital farming technologies and is typically provided by them for free to the companies developing the digital products (Bronson & Knezevic 2016). Some authors therefore argue that farmers are now partially transformed into digital labourers, generating data through their engagement with precision farming technologies and providing agri-tech companies with essentially free labour as well as new avenues for their own surveillance (Rotz et al 2019b; Stone 2021). The commodification of farmers' data has opened up a new frontier of accumulation in agriculture (Stock and Gardezi 2021; Fraser 2018). And while there are still considerable doubts about whether digital technologies really deliver on the promises of increased precision and control over nature (Heimstädt 2023; Visser et al 2021, Guthman and Butler 2023), data productivism and agricultural productivism have become the 'twin engines' of the contemporary food system (Montenegro de Wit and Candfield 2023, 408) and characterise the digital transition of factory farming.

The dominant vision of digital agriculture is not only one of greater precision and control over nature, but also a vision of agriculture without workers. Imaginaries of the

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digital future of farming often depict fields and orchards filled with robots and drones instead of farm workers (Baur & Iles 2023; Prause 2021). Existing studies, mainly from the global North, show that perceived labour shortages and rising labour costs are important reasons for farmers to invest in automation (Carolan 2020b). Concerns have been raised about the potential of robotization to replace farm labour and the consequences of such a shift for rural areas (Rotz et al 2019b; Rose et al 2021). However, the full robotization especially of labour-intensive crops is still a long way off (Legun and Burch 2021, Prause 2021). Fruit and vegetable farming, sugarcane production, tea plantations, palm oil plantations, commercial cotton farming or the global flower industry all rely on huge numbers of farm workers (Pye 2021; Hall et al 2017). It is estimated that 1.3 billion people work in agriculture worldwide, accounting for around 26% of global employment (Worldbank 2021). The global land grab that began during the financial crisis of the mid-2000ds has contributed to the further dispossession of smallholder farmers in the global South and points to the expansion of industrialised and plantation agriculture that caters to global agri-food commodity chains (Hall et al 2017; McMichael 2012; Benanav 2015). For the foreseeable future, farm labour will remain an important component of industrial agriculture. Therefore, there is a need to understand how the transition from industrial to digital-industrial agriculture affects agrarian labour.

In a previous article, I explored how digital technologies are being introduced not only to replace workers, but also, to control workers in agriculture by introducing methods of digital Taylorism (Prause 2021). However, I failed to grasp how these new attempts to control labour relate to the widespread attempts to control nature through precision technologies. As the critical literature on digital agriculture points out, increased control over natural processes and the spatial and temporal heterogeneity of agriculture is the core promise of the digital revolution in agriculture (Miles 2019; Visser et al 2021; Clapp & Ruder 2020).

This paper explores how digital technologies are being used in an attempt to increase not only the control over nature but also over labour in agriculture. I ask how these two processes are interconnected and what the technological shift from industrial to digital-industrial agriculture means for the way farm labour is organised, managed, and controlled.

I introduce the notion of the 'digital factory farm'. The term is inspired by recent work on digital capitalism and labour processes (e.g. Fuchs and Chandler 2019; Altenried 2020, Staab 2019, Kitchin 2023). I start from the notion of the 'digital factory' as a new labour regime that has become characteristic of a wide range of production processes in digital capitalism, including Amazon warehouses, transport or food delivery platforms, crowdwork, social media or gaming (Altenried 2022). I will demonstrate that the digital factory in agriculture manifests in different forms, best understood through the lens of capitalist logics interacting with nature. Building on the work of Boyd et al. (2001) and Malm (2016), I aim to expand the concept of the digital factory by examining it through the frameworks of formal and real subsumption of labor and nature. As I will show, the digital factory farm 1) offers new ways to deepen the real subsumption of labour and nature 2) attempts to intensify the longstanding process in industrial agriculture of using really subsumed nature to subsume labour, and 3) now also uses really subsumed labour to intensify the subsumption of nature. Empirically, I contribute to the critical debate on digital agriculture by uncovering the digitally mediated mechanisms of labour control in digitalised farms and the drivers behind the adoption of digital technologies in commercial fruit farming. I illustrate my arguments with a case study of digital technologies for industrial fruit farming in the Western Cape.

The article is structured as follows: In the next section, I develop the concept of the farm as a digital factory. After the methods section, I outline the context of my case study—the fruit farming sector in the Western Cape—and identify key drivers for the adoption of

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digital technologies in South Africa. I then delve deeper into my case study to illustrate how the digital factory farm operates. These insights inform a discussion on the implications of introducing digital technologies for managing and controlling farm labor in digital-industrial agriculture. I conclude with suggestions for further research to enhance our understanding of the digital revolution's impact on farm labor and the functioning of the global agri-food system.

Conceptualising the digital factory farm

In order to understand what the shift from industrial to digital-industrial agriculture means for attempts to control farm labour, I draw on the broader Marxist discussion of the 'factory'. I understand the factory as production infrastructures characterised by different technological and spatial configurations that organise the production process. Working with industrial machines means that the labour process is organised around the rhythms, times and needs of the machine, rather than the needs of the workers (Marx 2007 [1867]). Through its design and in combination with particular styles of management, the factory produces labour regimes that divide, control and discipline labour and undermine workers' autonomy (Marx 2007 [1867]). Marx also refers to this factory logic as the shift from formal subsumption to real subsumption of labour under capital. Formal subsumption occurs when capitalists take control of labour processes that originate outside of or prior to the capital relation through the introduction of a wage relation. The real subsumption of labour goes a step further. Here, labour processes are internally reorganised to meet the dictates of capital, usually through the use of some form of machinery or technology (Fuchs 2018). During the Fordist era of capitalism, the real subsumption of labour was deepened by a new factory setting, that came to be known as Taylorism (Braverman 1974). The technologically enabled pacing of the labour process through the assembly line, pioneered in the Ford factories, was combined with

technologically enabled constant surveillance and performance measurement, as well as small tasks and detailed instructions based on a machine- enabled division of labour, hierarchical control, and close supervision of workers (Smith 2015).

The shift to digital capitalism has given rise to new regimes of digitally mediated workplace surveillance, which some authors refer to as "new" or "digital" Taylorism. Through a combination of software and machines, digitally mediated production systems offer new modes of standardising of tasks, the means of algorithmic management, surveillance, and automated measurement of results and feedback to organise the labour process (Altenried 2022). Digital systems can track progress, automatically record the history of worker performance, calculate what is theoretically possible to achieve in a given time under ideal conditions, and use this to set targets (Kitchin 2023). Elements of work are divided into distinct tasks that are constantly monitored and measured to "*maximise output, eliminate 'idle time' and increase the pace of work so that nominal working hours remain the same but real working hours are lengthened, thus increasing the absolute surplus value*" (Kitchin 2023, 145). As such digital technologies allow the factory logic to be extended beyond the walls of the classic industrial factory buildings into new realms such as platform or gig labour, Amazon warehouses or social media, creating the digital factory (Altenried 2022).

As McWilliams (2000 [1939]) work on factory fields in California in the 1930s shows, attempts to extend the logic of the factory into agriculture have been around since the beginning of industrialised agriculture. However, agriculture presents unique challenges to the establishment of factory labour regimes. A fruit or vegetable farm is spatially very different from the classic factory setting. It is large-scale and can be quite dispersed over a number of different fields over a wide area or spread out over hilly or mountainous landscapes. Such settings, as well as the tree canopy in the case of fruit farming, make farms

exceptionally difficult to monitor. This contributes to a constant monitoring problem in farm labour supervision (Coomes & Barham 1994). Everyday forms of resistance, such as shirking, hiding, and stealing part of the produce, sideline activities and foot-dragging, are therefore major challenges for labour control in agriculture (Scott 1989). In addition, the seasonal nature of harvesting means that the labour requirements of modern farms are highly variable. Farm owners need to have access to cheap and readily available short-term labour. Although farm labour is often not formally qualified, many of the basic manual tasks do require some level of expertise (Legun et al 2022; Mitchell 2023). This is particularly true in the contemporary globalised agro-food system, where commercial agriculture is deeply embedded in global value chains with supermarkets imposing rigid quality standards (Akram-Lodhi 2019). (Informally) skilled farm workers therefore have some leverage vis-à-vis their employers even in contexts where labour is cheap and abundant (Selwyn 2009).

Agriculture differs from industrial or service sectors not only in its spatial and place-based qualities. It's direct reliance on living nature also means that capital accumulation in agriculture depends on the natural growth cycles of plants. Yields and growth cycles are always variable and hard to predict due to weather or pests. Crops are perishable and vary in quality. And machinery must be deployed in a way that adjusts to the landscape. Thus, the predictability and calculability of production, which are central to increasing productivity under capitalist competition, are constantly challenged in agriculture (Goodman et al 1987; Boyed et al 2001; Mann 1990).

The industrialisation of agriculture is therefore not just a history of attempts to overcome challenges of labour control, but also to overcome challenges of controlling and managing nature. Industrial agriculture has devised a range of technologies and inputs, such as synthetic fertilisers, pesticides, and herbicides (Bernes 2018), farm machinery, farming techniques, spatial organisation (Baur and Iles 2022), and the manipulation of the genetical

material of plants (Kloppenburg 2005), which allowed for the *'systematic increase in and standardisation of biological productivity (i.e., yield, turnover time, metabolism, photosynthetic efficiency)'* (Boyed et al 2001: 564). These technological breakthroughs transformed farms into settings that resemble *'open-air factories'* (Benanav 2015, 114).

Boyd et al (2001) call this the shift from the formal subsumption of nature to the real subsumption of nature. Analogous to Marx's distinction between the formal and real subsumption of labour, the term formal subsumption of nature refers to natural processes and products that are simply exploited, without *'capital controlling, intensifying, manipulating or otherwise "improving upon nature"'* (Boyd et al 2001: 562). This was the case in non-industrialised agriculture, where conservation, recycling of organic waste, crop rotation, mixed cropping, and legumes planting all contributed to the formal subsumption of nature. The industrialisation of agriculture has shifted this mere exploitation of natural processes towards the recreation of nature as a highly controlled and manipulated system. Capital actively intervenes in the natural processes to eradicate the autonomy of nature and integrate it into the process of valorisation (Mau 2019).

The contribution of Boyd et al's (2001) is essential for understanding how capital relates to nature in industrial agriculture, but they treat the real subsumption of nature as a mere analogy to the real subsumption of labour. Malm (2016) on the other hand, argues that the real subsumption of nature can enable the real subsumption of labour (not only in agriculture, but as part of the general process of capitalist development). His analysis of the shift from water power to coal power in the British textile industry shows that 'really subsumed nature' in the form of easily transportable, stockable, and usable coal power enabled the real subsumption of labour (Malm 2016, 306). Coal allowed capitalists to build their factories in the city, where they had access to a large and cheap labour force. They could run their factories on their preferred schedule, as they were now independent of the various

forces and locations of water streams. So, the real subsumption of nature and labour are not two independent processes, but the former makes the latter possible.

Studies of the industrialisation of agriculture in California have made a similar point. They show that the introduction of new harvesting support machines in the 1960s, which brought significant time savings in the harvesting process, was only possible through new forms of weed control, the introduction of new crop varieties and a reorganisation of the fields through precision planting (Guthman 2004; FitzSimmons 1986, Mitchell 2023, Baur & Iles 2022). A deepening in the real subsumption of nature enabled a deepening in the real subsumption of labour.

I take this argument one step further. Both Malm and the studies of labour processes in Californian agriculture point to the way in which nature is used to further subsume labour in agriculture. I argue that in digital agriculture this dynamic also works in reverse: labour is now used to deepen the real subsumption of nature. We see a continuation and digital update of the use of really subsumed nature to deepen the real subsumption of labour. But we also see, and this is new, that the real subsumption of labour is being used to deepen the subsumption of nature in an attempt to fulfil the promises of precision farming. This is what I call the 'digital factory farm'. Digital technologies do more than simply control labour through by introducing digital Taylorism on farms. They also do more than introduce precision farming techniques. The digital factory farm provides new avenues for an intensification of the real subsumption of both labour and nature, as well as new forms of interconnection between these two processes.

Methods

I explore the workings of the digital factory farm through a case study of the use of digital technologies in industrial fruit production developed in the Western Cape, South Africa. The

Western Cape is the biggest income generating province in South Africa's commercial farming sector and therefore an important market for new digital technologies. Out of 40.122 commercial farms in South Africa, 6.937 commercial farms were registered in the Western Cape (Census of Commercial Agriculture 2017). Wine grapes (approx. 86.544 hectares), apples (approx. 21.533 hectares) and table grapes (approx. 12.252 hectares) are the most important crops produced in the Western Cape in terms of hectares planted (BFAB 2022). Most of the produce is exported to Europe and increasingly also to China and the Middle East (Partridge et al 2020). Those exporting to Western countries are under increasing pressure to produce in a socially and environmentally sustainable manner, which is reflected in several certification schemes for the industry, such as the Wine and Agricultural Ethical Trade Association (WIETA) or the Sustainability Initiative of South Africa (SIZA).

I collected the data for my case study during a total of six months of fieldwork in the Western Cape in 2022 and 2023. I conducted a total of 38 interviews and three focus group discussions. Of particular relevance to this article are two in-depth interviews with senior executives of agtech companies that develop and sell digital technologies for fruit production, and eight interviews and three focus group discussions with fruit farmers and fruit packhouses managers. Most of the interviews were conducted face-to-face, and the field notes taken during farm visits provide important additional data points. The farmers I interviewed produced and packed apples, table grapes, wine grapes, citrus and stone fruit. All produced mainly for export markets and all of them used some digital technology in their operations. Valuable additional information came from interviews with three farm workers and participatory observation during field visits with a farm workers' union and a farm workers' NGO, who I accompanied each for three days in their work on the farms in the Western Cape. I was not able to interview farm workers who worked on the farms that were owned or managed by the farmers I interviewed. I therefore lack a thorough understanding of

how farm workers engage with the digital technologies used by these farmers. This is certainly a weakness of the data set. However, my research focuses less on changes in the labour process as such, or workers' responses to digital technologies, and more on attempts to control farm workers and natural processes in agriculture. I believe that my data provides a privileged insight into the mechanisms of control that these technologies enable, even if the mechanisms of resistance employed by farm workers remain largely in the dark.

Digital fruit farming in the Western Cape, South Africa

Digitalisation has entered the South African agricultural sector in the early 2000s. No data are yet available on rate of adoption of digital technologies in South African agriculture. Interviews with growers' associations in the fruit sector indicate that the use of digital technologies is limited to large commercial producers who export to markets in Europe and the USA, and is not yet ubiquitous in South Africa's industrial fruit farming sector (interview, deciduous fruit grower association, 05.12.2022, Stellenbosch; interview, table grape farmer, 18.11.2022, online). In the smallholder sector, digitalisation is barely present at the production level, and even medium-sized farms don't seem to be investing much in digital technologies (interview, professor University of the Western Cape, 22.11.2022, Cape Town). On the one hand, large-scale commercial, export-oriented fruit farming in South Africa appears to be adopting digital technologies sold on the global agtech market. South African farmers learn about the latest technological developments and purchase new machinery and technologies at international fruit farming conventions such as fruit logistica in Berlin in order to remain internationally competitive (interview, table grape farmer, 18.11.2022, online; interview tech start-up, 23.11.2022). On the other hand, the digital technologies used on the production side in the orchards and vineyards are largely developed by local South African start-ups. In the Western Cape, a local innovation system has developed around

digital agricultural technology, bringing together South African start-ups, producer associations and research institutions, many of which are linked to the University of Stellenbosch. Farm owners report that they value the availability and support that these start-ups offer as well as their understanding of the local context in the Western Cape and their ability to provide technological solutions to local challenges (interview, table grape farmer, 18.11.2022, online; interview table grape farmer, 13.04.2023, De Doorns).

Two key issues that are driving the digitalisation of fruit farming in the Western Cape emerged from the interviews: Supply chain pressures and labour concerns. The fruit growing sector in South Africa had received extensive protection and support during the apartheid regime. After the transition to a democratic regime in 1994, South African fruit producers were suddenly exposed to global competition – particularly from other fruit-producing countries in the Southern Hemisphere such as Chile, Peru, and New Zealand – and increasingly powerful and coordinated European supermarket buyers (Alford & Philipps 2018, 106). Fruit producers, particularly those exporting to the European market, are under increasing pressure to meet high environmental and quality standards and to provide detailed information about the origin of the fruit. Farmers emphasise that digital technologies allow them to track their products in more detail and to gain more control over their farming and export operation (interview, table grape farmer, 13.04.2023, De Doorns; focus group, apple-pair cooperative, Grabouw; interview table grape, blueberry, and citrus farmer, 23.11.2022, Stellenbosch).

The second driver is farmers' concerns about farm labour. During apartheid labour relations in South Africa's agricultural sector were largely unregulated and characterised by a mixture of violent, coercive, and paternalistic relationships between farm workers and farm owners (Ewert & Du Toit 2005). The transition to a democratic regime in 1994 introduced progressive legislation that aimed at guaranteeing the rights of farm workers', including an

annually adjusted minimum wage (Devereux 2020). Farm owners have responded to the pressures of increased labour regulation, agricultural market deregulation and increased supply chain pressures by casualising their work force (Alford & Philipps 2018). Commercial farms now often operate with a relatively small permanent core workforce, who typically enjoy decent working conditions, and an additional seasonal work force, who are hired on a temporary basis, sometimes through labour brokers, and often receive lower wages and no additional benefits. Furthermore, the Department of Labour still lacks the capacity to fully monitor and enforce existing labour laws. Violations of farm workers' rights are frequently reported by NGOs and farmworker unions (Alford & Philipps 2018; Devereux 2020). The farm worker strikes 2012/2013 demonstrated the strong grievances of farm workers, which remain prominent in post-apartheid South Africa's fruit farming sector. Farm workers successfully disrupted the fruit supply chains in the Western Cape and succeeded in securing an increase in the minimum wage from R69 to R105 per day, applicable to the entire commercial fruit and wider agricultural sector (Alford & Philipps 2018; Wildermann 2015). By 2024, the minimum wage in the agricultural sector had increased to R27,58 an hour or R 220,64 for an eight-hour workday (Labourwise 2024).

Although agricultural labour is still comparatively cheap in South Africa and rural unemployment rates are high, rising labour costs and labour management are key concerns for farmers. Approximately 209.000 people were employed in the agricultural sector in the Western Cape in 2019, an increase from 186.997 that were recorded in the 2017 census (Census of Commercial Agriculture 2017; Partridge et al 2020). 94% of farm workers are black or 'coloured' (Partridge et al 2020), while commercial farms are predominantly owned by white South Africans or national or international companies (Sihlobo & Kirsten 2021). Fruit farming in the Western Cape is therefore still highly dependent on labour. In fruit farming, labour is the largest farm expense (interview table grape farmer, 18.11.2022, online;

interview table grape, blueberry, and citrus farmer, 23.11.2022, Stellenbosch). Farmers did not mention the 2012/2013 labour unrests as a motivation for investing in digital technologies. However, concerns about the rising minimum wage, which will further increase their labour costs, low labour productivity and low labour quality were frequently mentioned as reasons for investing in digital technologies (interview table grape farmer, 18.11.2022, online; interview blueberry farmer, 26.06.2022, online).

Fruit farming as digital factory

Large-scale commercial fruit farms in the Western Cape are now using a range of digital technologies, that as I will show, serve three main functions: increasing farm productivity through precision agriculture, increasing traceability and optimising the labour processes and labour productivity. These three functions are intricately intertwined in the design and use of the different technologies, thereby deepening, and linking the real subsumption of labour and nature together.

Precision agriculture and the real subsumption of labour

As previous studies have pointed out, really subsumed nature, for example through weed control or genetically modified crop varieties, has long been used to optimise labour processes and labour control in industrial agriculture (Mitchell 2023; FitzSimmons 1986). Precision technologies reinforce this long-standing trend. In the Western Cape, the most commonly used precision farming technologies reported by interviewees were offered by two South African start-ups that collect and combine multiple data points from the farms in order to enable a more precise management of the farming operations. As a senior manager of one of the start-ups explains: "*Now we have [data on] the soil, which is one of the most important things a farmer has, we have your plant growth, from the satellite imagery, and now we have our fruit loading that we do with the cameras*" (interview agtech start-up precision

agriculture, 23.11.2022, Stellenbosch). The combination of these different data points on an orchard allows farmers to manage their orchards' irrigation systems, fertiliser application and soil composition more precisely. "*We have now the ability to apply fertilizer at a variable rate for higher vigour, lower vigour. We can up or we can down the volume of fertiliser needed. And it is really accurate. The accuracy is one inch by one inch*" (interview, table grape farmer, 18.11.2022, online). The aim hereby is to increase yields, but equally important is the ability to manage the orchards for greater uniformity (interview table grape farmer, 13.04.2023, De Doorns; interview table grape, blueberry, and citrus farmer, 23.11.2022, Stellenbosch). South African soils are highly variable, often even within the same field. Precision agriculture technologies promise to allow farmers to standardise their soils across their fields and orchards, and then use irrigation schedules and fertiliser inputs to manage growth rates and ripening cycles so that each block or variety reaches its optimum point for harvesting at about the same time. This uniformity in orchards is important to growers as it allows for easier irrigation management, easier planning of production logistics, but also easier labour management, a reduction in overall labour requirements and a lower skill level of the workers. "*Different soil types make it difficult to manage a specific orchard homogeneously. Because […] you have to farm as a unit. […] And then when you prune it, you prune it the same way, when you harvest, you harvest everything the same way*" (Interview table grape, blueberry, and citrus farmer, 23.11.2022, Stellenbosch).

Uniform orchards allow faster harvesting, as workers spend less time sorting through oranges on a tree to pick only the ripe ones for example, and can harvest whole trees indiscriminately. It also shortens the weeks in which fruit must be harvested, reducing the number of weeks farmers need to employ their seasonal workforce (field protocol, farm visit, Laignsburg, 23.03.2023). Uniform orchards thus allow for intensification of the labour process and a further de-skilling of farm workers, who no longer need the skills to separate

ripe from unripe fruit for example. Farmers are combining precision farming technologies with new crop varieties developed to reduce labour: *"The big driver amongst breeders is to produce more labour friendly varieties. That means varieties higher in yield, easier to grow, that require less manual input and handling"* (Interview, table grape farmer, 18.11.2022, online). And they also use manual labour to further increase the homogenisation of the field: *"With regards to manipulation, we trim the berries, make sure the bunches are exceeding a specific length, or they have a desired shape and form, and they are homogeneous. That is manual precision farming"* (Interview table grape, blueberry, and citrus farmer, 23.11.2022, Stellenbosch).

The use of digital technologies for precision farming is an attempt to monitor, control, and homogenise nature in industrial farming. This precision management of nature offers new means of intensifying, simplifying and further standardising labour processes on farms, and thus to deepening the real subsumption of labour under capital. How successful these new attempts to use nature to subsume labour on digital factory farms will be in the long run remains to be seen. However, commercial fruit growers have high hopes for precision technologies. As one farm owner puts it, *"we can't mechanise and digitise the actual working of the grapes itself. But we can measure and digitise everything around it to make it as productive and cost-efficient as possible."* (interview table grape farmer, 13.04.2023, De Doorns).

Digital Taylorism and the real subsumption of nature

Digital technologies for precision agriculture are an update of a long-standing tendency in capitalist agriculture to use the subsumption of nature to deepen the subsumption of labour. However, digital factory farms are characterised by a second dynamic, where digital technologies developed to control labour, are now also being used to deepen the real

subsumption of nature. In the Western Cape, some farmers are using digital technologies that track the individual performance of farm workers, trace produce back to the plot and sometimes even the tree from which it was harvested, and collect data on the state of the farm. As one table grape farm owner in the Hex river valley explains: *"from the picking side, the grapes are picked into crates, which every guy who's picking puts a label on, that is then scanned when it comes into the packhouse. So that is just registered against him, weighed, also checked for quality, if he picking the right standard."* (interview table grape farmer, 13.04.2023, De Doorns). One of the South African start-ups developing the technologies to track workers' performance calls this 'precision harvesting'. The technology offered by the start-up not only tracks the boxes harvested to an individual farm worker, but combines this with a GPS tracker that each farm worker wears, so that the GPS location of where the farm worker harvested is recorded. This allows for an even finer traceability to specific parts of a field or even individual trees. All this data is fed back to a dashboard that the farm manager can access. This allows the farm manager to see the location and performance of each individual worker in real time (interview, agtech start-up, 23.11.2022, Stellenbosch) *"So if you see grapes coming in where the colour is not right, you can go back to that person, who has been cutting and say (…) this needs to be addressed or they must leave because it is causing problems"* (interview table grape farmer, 13.04.2023, De Doorns). This form of digitally enabled surveillance can inform decisions about whether workers keep or lose their job. It also gives farm managers the tools to adjust their wage and incentive structures. Farm workers in South Africa are often paid in a combination of a minimum hourly wage and a piece-rate wage (Zahn et al 2022). Farm managers set a target for how many crates a worker must harvest per hour to 'earn' the minimum wage. For each additional box, the worker can receive a bonus. However, farm workers often report that the targets are set so high, that they can barely meet them (Zahn et al 2022). Through data-driven monitoring, farm managers can

compare the performance of each farm worker with that of his or her peers, allowing them to adjust benchmarks for expected output per hour paid. The fastest workers can thus become the new standard for the entire workforce, further intensifying the labour process. Surveillance technology is also introduced into other aspects of fruit farming, such as tractors used to spray pesticides. *"We spray a lot at night, so you can trace the tractor and make sure it's sprayed everywhere. You can make sure they didn't spend an hour sitting at the fuel station chatting to each other. One was picked up where they went home at 12 o'clock and came back at 3 o'clock. So they went home and slept, but are clocking." (*interview table grape farmer, 13.04.2023, De Doorns*)".*

However, these digital tracking tools are not only used to control labour and optimise labour productivity in a digital Taylorist way. By tracking their own output and the location of the trees they harvested, farm workers are also doing the unpaid work of collecting data for supply chain traceability and precision agriculture on farms. Through the system of trackers and barcode stickers that the workers put on every crate, box and pallet, it is now possible to trace a box of grapes bought in a European supermarket back to the farm, the plot and the person who picked it (interview table grape farmer, 13.04.2023, De Doorns). For farmers who have to meet the strict quality standards of European supermarkets, this is key to managing the quality of their produce.

When the tracking of harvested produce is combined with GPS trackers, it also provides a way to more accurately manage the trees in the orchard. By using the trackers and scanners during tasks such as harvesting or pruning, farm workers collect data on how plants and fields are performing. This additional data collection allows farm managers to implement new forms of precision agriculture on farms. The data collected by the workers is used to create yield maps, and the software provided by one of the South African start-ups gives an overview at the end of the season of the average yield per hectare, but also of the variability

of harvests within fields, and identifies parts of the orchard that are "underperforming" (Agtech start-up, company brochure, published 2021). If an area of the orchard is "underperforming", farm managers could, for example, experiment with different forms of irrigation or fertiliser in that area. In addition , the ability to trace harvested boxes back to specific trees or areas in the field allows farm managers to know where certain bugs or pests are located in the field, should they be found in the boxes. The scanners on the tractors allow for an optimisation of pesticide spraying as well as for a tighter control of farm workers. The promise of these technologies is that "*knowing the exact yield, productivity and performance of each tree as well as employee gives you undreamt of power to increase profits over time and improve productivity*" (Agtech start-up, company website, accessed 08.11.2023). Whether this promise will be fulfilled remains to be seen. However, the introduction of these technologies on some South African farms suggests that attempts are being made to make this the new reality of commercial farming.

These digital technologies not only facilitate the introduction of the classic tools of digital Taylorism into commercial agriculture. They also offer new ways of creating value by extracting additional unpaid labour from agricultural workers in the form of data collection that enables traceability, optimisation of supply chain management and precision farming. These digital products therefore contribute to a deepening of the real subsumption of labour, but they also contribute to an intensification of the real subsumption of nature through data collection for precision agriculture. They increase the surplus value for farm owners by intensifying the labour process and the unpaid work performed by farm workers, which enables more precise management of nature on farms. This exemplifies the entanglement of the subsumption of labour and nature in the digital factory farm.

Farm labour and the digital factory farm

The digital factory has been introduced as a term to denote the extension of the factory logic of labour control and management to workplaces outside the walls of the classical industrial factory by means of digital technologies. My case study of digitised fruit farming in the Western Cape showed that farm owners and technology start-ups are trying to implement the logic of the digital factory on farms. Digital technologies, such as GPS trackers worn by farm workers or fitted to tractors, are helping to overcome long-standing problems of labour monitoring in agriculture. Orchards and spatially dispersed fields have always provided cover for everyday forms of resistance by farm workers, such as slacking off, stealing produce, counting time as work when taking a break, or sneaking off the farm altogether. Wearable trackers and scanners attempt to make them visible to management at all times. This is an important change from classic Taylorist methods, as these technologies now allow control of a spatially dispersed workforce outside the classic factory setting. The digital devices attempt for real-time control, feedback and correction of farm workers. They provide new tools for intensifying the labour process, increasing surplus value for capital and deepening the real subsumption of agricultural labour.

In the digital factory farm, the real subsumption of labour is also deepened through precision agriculture and 'really subsumed' nature. Precision farming attempts to precisely manage plant growth, ripening times, and harvesting cycles, thereby attempting to bring agriculture closer to the capitalist ideal of nature as a machine that produces standardised and scheduled products in a factory-like setting. Digital technologies seek to overcome the long-standing challenges of capitalist agrarian production, such as the lack of predictability, calculability, and uniformity of production, thereby deepening the real subsumption of nature. Fields and orchards have long been laid out in ways to spatially organise the labour force and intensify labour processes in agriculture (Mitchell 2023; FitzSimmons 1986). Precision

farming deepens this logic of labour management and rationalisation through nature by promising more precise management of plant growth, resulting in more standardised and homogenised fields and plantations.

However, while the literature on labour processes in industrialised agriculture has already highlighted how nature is used to deepen the real subsumption of labour, my case study shows that this logic also works the other way round. By deepening the real subsumption of labour through digital technologies, farm workers now provide free labor in collecting the data that facilitate precision farming as well as workers' own surveillance. Farm managers gain the insights to implement precision agriculture and optimise supply chains and their operations by extracting the unpaid labour of data collection from farm workers.

The critical literature on digital agriculture already points out that digital technologies are often used to achieve greater homogeneity in fields rather than (bio)diversity (Duncan et al 2021; Bronson 2019; Stock and Gardezi 2021). The literature also suggests that producers are monitored and their data extracted when using digital technologies (Stone 2023, Prause et al 2021; Bronson and Knesevic 2016). The digital factory farm allows us to see that these processes are not separate but, deeply intertwined in the design of digital technologies and the wider transition to digital-industrial agriculture. Importantly this paper highlights, that this logic applies not only to farmers working their own land, but also to farm workers. In analysing the transition towards digital-industrial agriculture, I believe it is important to ask what the introduction of new technologies means for nature, farmers AND workers. We need to recognise that technologies that seem to be aimed at more precise management of nature can also have consequences for those who work the land, and vice versa.

The Western Cape case study has shown that the digital factory farm is being introduced as a response by commercial growers in response to the twin pressures of lead

firms demanding stringent product quality standards and detailed traceability without paying higher prices for the produce, and rising production costs in South Africa, partly due to a rising minimum wage. Digitalisation is not replacing an industrial model of agriculture based on large standardised fields and orchards, chemical fertilisers, pesticides, modern breeding techniques, and a large seasonal workforce. On the contrary digital technologies integrate with and stabilise this model of intensive industrial production, which is typical of today's agri-food system. Digitalisation seeks to optimise this model by rationalising the labour process and increasing the uniformity and quality of products, allowing commercial farmers to make a reasonable profit margin despite high supply chain and price pressures.

Given the lack of research on digital technologies and their impact on labour processes, it is difficult to say, whether the attempts to implement the digital factory farm are specific to the South African context or something that is now being introduced more generally in highly globalised fruit commodity chains. My hunch is that South Africa is not unique in its development of digital factory farm settings, as many commercial producers in the global South face similar pressures from global lead firms and rising production costs. I would expect a version of the digital factory farm to also emerge among export-oriented producers in the global South, for example in Peru or Chile. The few existing studies of digitalisation and fruit production in the global North suggest a greater commitment to automation and robotics than what I have found in South Africa (Legun and Burch 2021; Rose et al 2021). This makes sense given the fact that these producers face labour shortages rather than an readily available large seasonal workforce, as is the case in South Africa.

While it remains unclear whether the promises of the digital factory farm to intensify and link the real subsumption of labour and nature will be successful, the attempts described in the Western Cape case study suggest that digital technologies may have the potential to weaken farm workers' ability for resistance. Everyday forms of resistance have always been

important tools in farm workers' struggles. The constant surveillance on digital factory farms has the potential to prevent these forms of resistance. Furthermore, the introduction of digital technologies in agriculture also poses new challenges for farm workers' organisations which, at least in South Africa, have so far been largely unaware of the issue (Interview farm worker NGOs, 10.06.2022, Stellenbosch and 16.04.2023, Cape Town). If digital tracking tools are widely used in the future, dismissals may be increasingly based on the digital data of workers' performance. How will farmworker unions get access to this data? And if farm workers are constantly being digitally monitored, how can labour organising function in agriculture? Farm worker organisations often rely on (clandestine) visits and conversations with workers in the fields and plantations, especially in the South African context where many farmworkers are still housed on the private farmland of the farm owners (Interview farm worker NGOs, 10.06.2022, Stellenbosch and 16.04.2023, Cape Town).

How successfully, and comprehensively digital factory farms in South Africa or beyond enact these new forms of control over labour and nature in practice requires further study. What I have described are the attempts by digital tech companies and farm owners to deepen and draw together the real subsumption of labour and nature. However, my data does not allow to explore the response of workers to these technologies. Other studies of labour in digital capitalism in other sectors have shown that workers are finding new and creative ways to resist the digital measurement and surveillance of their work. Old methods such as strikes also remain an important tactic for workers, for example in Amazon warehouses, to fight for better wages and working conditions (Altenried 2022; Fuchs et al 2021). Contributions from digital agriculture literature have also cast doubt on the promises of precision agriculture (Heimstädt 2023; Visser et al 2021). They question whether digital technologies are really able to deliver a more precise management of nature, and how useful all the data collection real is. Indeed, a long-standing literature on capital accumulation in agriculture emphasies

that capital has never been able to completely eliminate the irregularities of nature and that unintended consequences often follow the attempts to fully subsume nature under capital (Lewontin 2000; Bernes 2018).

Conclusion: Digital factory farms in contemporary capitalism

The notion of the "digital factory farm" presented in this article highlights how farms are sites where the significant effects of digital technologies on the real subsumption of labor and nature become evident. These technologies provide new ways to enhance capital's efforts to reshape both labor and nature. The digital factory farm integrates recent discussions on the digital factory (Altenried 2022), theoretical insights into the real subsumption of labor and nature (Malm 2016; Mau 2019), and research on the role of nature in organizing labor processes within industrial agriculture (Bernes 2018; FitzSimmons 1986; Mitchell 2023; Baur & Iles 2022).

This concept extends existing frameworks by demonstrating that digital technologies can facilitate new forms of labor control through digital Taylorism and new methods of controlling nature via precision farming. Moreover, these technologies deepen the connections between these processes. They modernize long-standing practices of using nature to subsume labor and enable the exploitation of agricultural workers' unpaid data-gathering efforts to further enhance the real subsumption of nature.

While contributions on digital Taylorism and the digital factory have correctly pointed out that *"networked devices, sensors, and apps have moved Taylor's time and motion studies outside the enclosed spaces of factories and distribution centres and into urban spaces of the logistical city"* (Altenried 2022, 159), these devices have also moved these logics into the rural spaces of global capitalist production, where they become intricately linked with the management and control of nature. The development of digital factory farms herby

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contributes to stabilizing global production networks and an industrialized way of farming, and it introduces new forms of labour control on fields.

However, more research is needed to understand the implications of the digital factory farm. First, we need to investigate whether the attempts to build digital factory farms in the Western Cape and the promises made by technology companies are becoming a widespread reality in agriculture, or whether they will never materialise on a larger scale. Secondly, the response of farm workers to these new attempts at digitally mediated labour control needs to be explored. Many of the digital technologies may in fact be useless for labour control because farm workers have found new ways to resist them. Third, it remains unclear how successful these technologies are in managing nature more precisely, and what unintended consequences the use of precision farming techniques might have. Fourth, case studies in other contexts could shed light on whether the South African case is typical or unique. Are we seeing the establishment of digital factory farms in other countries where fruit production is also part of highly globalised commodity chains, or not? This would allow us to assess whether we are witnessing a transformation of the labour process on a global scale or whether the digital factory farm is a short-lived experiment. Finally, I think it is important to further investigate what happens to the data that farm workers now produce through their unpaid labour. Is it only the farm owners who use and have access to this data, or do the agtech companies or supply chain actors such as logistics companies or supermarkets also have access to and use this data? This could tell us more about how digital factory farms are changing power relations beyond the farmworker-farm owner dynamic within highly globalised commodity chains.

Declaration of interest
No conflict of interest.
Ethics approval

Upon request, the Albrecht Daniel Thaer Institute at the Humboldt University in Berlin stated that formal ethical approval for the fieldwork was not required if the anonymity of all participants was guaranteed and informed consent was obtained prior to the interviews. Informed consent was obtained by explaining the research project and the use of the data obtained in the interviews prior to the interview process. All interviewees were asked if they consented to the interview being recorded. If they gave consent, this was recorded on the audio file; if they did not consent, the information from the interview was documented through notes taken by the interviewer. All transcripts were then carefully anonymised. This included anonymising names, but also farm and company names.

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