Article

Weeds in action: Vegetal political ecology of unwanted plants

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Abstract

This paper presents a vegetal political ecology of weeds. Weeds have barely been analysed in the burgeoning field of 'more-than-human' scholarship, this despite their ubiquity and considerable impact on human social life. We review how geographical scholarship has represented weeds' material and political status: mostly as invasive plants, annoying species in private gardens and spontaneous vegetation in urbanized landscapes. Then, bringing together weed science, agronomic science and the critical geography of agriculture, we show how weeds ecology, weeds management and the environmental problems which weeds are entangled have critically shaped the industrial agriculture paradigm. Three main arguments emerging from our analysis open up new research avenues: weeds' disruptive character might shape our understanding of human-plant relationships; human-weeds relation in agriculture have non-trivial socio-economic and political implications; and more-than-human approaches, such as vegetal political ecology, might challenge dominant modes of considering and practicing agriculture.

Keywords

weeds, agriculture, more-than-human, vegetal political ecology, invasive plants, pesticides

I Introduction

Social scientists have explored how plants are actively present in different settings and how the biological characteristics of plants become essential players in human social life (Hall, 2011; Head and Atchison, 2009; Hitchings, 2003; Jones and Cloke, 2002; Whatmore, 2002). Those characteristics or material performances, what's been referred to as plantiness (Head et al., 2012), become entangled in the more-than-human social life, and thus 'become capable of affecting, displacing and transforming human bodies and conduct' (Brice, 2014: 946). For example, urban trees can act as relatively autonomous material presences shifting through time, identity and place configuration (Jones and Cloke, 2008). The lawn beautifies and shapes the meaning of American backyards and their gardeners' subjectivities when taking care of it (Robbins, 2007). In

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the agriculture realm, certain crops have been studied through this lens: cereal grains' particular qualities, of being legible and taxable, have been instrumental in state-making projects (Scott, 2017). On the contrary, cereals and other crops can be considered 'escape crops', that is, partly ungovernable due to characteristics that allow them to be hidden or to grow quickly (Scott, 2000). In Paraguay, soya beans led to regime change and a subsequent institutional arrangement to govern them, under the pressure of social movements claiming 'la soja mata' (soya kills) (Hetherington, 2020a). At a different scale, fruit ripening can 'precipitate a radical change in the tempo of working and social life' for the human actors involved at farms (Brice, 2014: 951).

Inspired by plant geographies, we focus on weeds, sparsely considered in more-than-human scholarship despite their ubiquity and considerable impact on human social life. Traditionally, weeds are defined as 'herbaceous plant[s], not valued for use or beauty, growing wild and rank, and regarded as cumbering the ground or hindering the growth of superior vegetation' (Harlan, 2012 quoting the Oxford English Dictionary). What makes a plant a weed is its undesirable presence in human activities (social definition) and its capacity to propagate (ecological definition). Weeds' 'biologically intimate' relation with humans (Harlan and De Wet, 1965) is reflected in the diverse human interactions with these plants, whether in humans surveying them, using them for aesthetical reasons, eating them, hoeing them or spraying them with herbicides. The central argument of this paper is that the interests and tensions over weeds' management and control, derived from weeds' outstanding biological capabilities, are at the heart of environmental politics at different locales and scales. At the same time, such dynamics contribute in fundamental ways to our understanding of human-non-human relations.

From cultural geography to environmental anthropology through landscape research, weeds have been mainly studied in their form as invasive or alien plants (e.g. Atchison and Head, 2013; Head and Muir, 2004; Robbins, 2004a). In urban areas, weeds have also attracted the attention of social scientists, for example, as desired targets for urban foragers (McLain et al., 2014; Nyman, 2019; Poe et al., 2014) or as disturbing signs of abandonment (Brownlow, 2006; Falck, 2016; Patrick, 2014). In addition, scholars studying human-plant relations in private gardens have often encountered weeds in gardeners' narratives (Power, 2005; Robbins, 2007; Sander-Regier, 2009). Surprisingly, weeds in agriculture have remained unexplored by critical geographical scholarship even though they are cross-cutting to many crucial dimensions studied in the field – biodiversity, soil erosion, debt, labour, pesticides or environmental governance and policy.

In the light of these gaps, in this paper, we develop a vegetal political ecology of unwanted plants, attending to weeds' worldmaking capabilities, with a particular focus on agriculture but also tracing the role of weeds more broadly in human-nature relationships. While political ecology has paid increasing attention to the active contributions of non-humans to environmental politics (such as Bakker, 1999; Barua, 2014; Jones et al., 2019; Kaika, 2004; Lyons, 2020; Phillips, 2020; Sundberg, 2011), the agency of plants has been largely neglected (with some notable exceptions such as Robbins (2007) or Hetherington, 2020a). The scant scholarship on vegetal politics (Head et al., 2014), exploring the role of plants' unique capacities in more-than-human geographies, in settings such as private gardens where particular, and quieter, politics are at play (e.g. Bhatti, 2006; Hitchings, 2003; Power, 2005; Sander-Regier, 2009). Consequently, Fleming has called for a 'vegetal political ecology', considering 'the impacts of plantiness on human-plant encounters, like vegetal politics does, but that further links this impact to resource politics and other broader environmental contestations, like political ecology does' (Fleming, 2017: 27). By paying attention to the impact of plants' biological characteristics on power-laden structures, this framework can bring the ecology to the front of political ecology (Turner, 2016; Walker, 2005).

The article proceeds as follows: Section II explains the nature and value of a political ecology approach to weeds. Section III reviews weeds' political relations as alien plants, as spontaneous vegetation in urban areas and their fringes and as plant companions to hobby gardeners. Section IV contributes to the human-weeds scholarship by analysing weeds as a pervasive element in industrial agriculture. We consider the relations between weeds' ecology, weeds'

management, the agrarian economy that weeds force, and core environmental problems which they are entangled with (pesticide pollution, biodiversity loss and soil erosion). In section V, we discuss the contribution of this vegetal political ecology of weeds along three threads of discussion. These relate to the ways weeds can shape our understanding of human-plant relationships, the centrality of weeds in agriculture, and the opportunity to expand more-than-human perspectives in agriculture. Last, we conclude by calling for new ways of thinking *about* weeds and *with* weeds, paying attention to the barriers that weeds impose and the interests that try to overcome those.

II Political ecology and weeds

Weed science studies weeds' biological characteristics and strategies to manage them (Anderson, 1996; Hatcher and Froud-Williams, 2017; Zimdahl, 2018; Ziska and Dukes, 2011). Among the former, the following is noteworthy: Weeds are highly reproductive. The number of seeds produced by a single weed can be in the hundreds of thousands. Moreover, weeds have highly effective seed dispersal mechanisms, from wind to animals, making them mobile and difficult to contain. Some are also capable of reproducing underground by rhizomes. Weeds' seeds are capable of staying dormant in the soil for more than 5 years. They germinate with changes in sunlight, humidity, pH, or oxygen, but particular adaptations prevent them from germinating simultaneously. These adaptations of weeds demand long-term weeding strategies rather than one-shot solutions. Moreover, weeds are capable of evolving traits to survive harmful stresses such as drought. Other weeds have developed multiple mechanisms that can confer resistance to chemical herbicides.

These outstanding biological capabilities have significant consequences for human social life, creating interests and tensions over weeds' management and control. However, the disciplines studying weeds interactions in human systems – primarily plants and weed science, invasive plant science and agronomic science – have mainly focused on weeds' biological characteristics and forms of containing them, leaving aside possible political implications (but see Kull, 2018; Sumberg and Thompson, 2012). Political ecology, as a cross-disciplinary framework for the study of human-nature interactions, has historically politicised human-plants interactions in fields such as forestry resources (e.g. Springate-Baginski and Blaikie, 2014), land degradation (e.g. Blaikie and Brookfield, 1987), or biodiversity conservation (e.g. Vandermeer and Perfecto, 2013). Concerning the latter, this includes understanding how capitalism disciplining of nature selects what is useful for its exchange value and eliminates what is useless for capital accumulation (Giraldo, 2019). In addition, political ecology has been used to unpack the social and material production of nature in cities or peri-urban environments, including parks (e.g. Argüelles et al., 2021), urban gardens (Calvet-Mir and March, 2019), or farmers' markets (e.g. Alkon, 2013). Part of this unpacking relates to the study of how environmental narratives are constructed and which effects they have on environmental change. For example, weeds (as a categorisation used to describe and order nature) reflect a particular construction of the environment, bringing further consequences to environmental governance. Last, political ecology recognises the interconnectedness between spaces and scales and ecological, socio-economic and political realms (Guthman, 2019; Tsing, 2015). In the case of weeds, this is central, as we will see in the next section.

With this lens, political ecology work on weeds has mainly been an attempt to unpack 'when and how the quotidian movements of plants and processes of ecological and attendant social change – that is, their occurrence and spread across landscapes – become phenomena characterised as weeds or weed invasions and thereby objects of contention and control' (Kull and Rangan, 2015: 487, see also Binimelis et al., 2009; Patrick, 2014; Robbins, 2007). The vegetal political ecology lens (Fleming, 2017) we are undertaking in this paper focuses precisely on those quotidian movements, on the spread across landscapes, to explain how weeds' agency, or their more-than-human capacities, gets entangled in the contentious environmental politics around unwanted plants.

The following section reviews scholarship exploring weeds' multiple connections in national biosecurity programs, private gardens and urban and peri-urban greening programs, acknowledging that these interconnected realms have diffuse boundaries. As weed seeds travel across multiple spatialities,

some of the dynamics, discourses and imaginaries presented below are also trans-local.

III Current perspectives on human-weeds relations

1 Weeds in national biosecurity plans

Invasive plant species have been equated to climate change and soil erosion as major global threats (McGeoch et al., 2010; Vitousek et al., 1997). An introduced plant species – accidentally or purposefully – might change local ecosystems by consuming groundwater, or making them more vulnerable to fire and flooding, ultimately causing important control and eradication costs. While the phenomenon of invasion is not exclusively human-driven (Mack et al., 2000), it has intensified by human mobility in the context of global trade (Hulme, 2009).

Invasiveness relates to three characteristics: origin, behaviour and impact (Kull and Rangan, 2015). The common narrative around invasive plants used by conservation organisations and governments suggests that local plants are the victims of other biodiversity-threatening species. Massive amounts of funding and careers are supported by this narrative (Chew, 2015). The modern field of invasion biology has focused chiefly on species and neglect the processes favouring invasion (Kull, 2018). However, a more critical stand reflects on how the status and identification of any species as an invader, weed or exotic are conditioned by structural circumstances, or, in other words, 'it is not species, but sociobiological networks that are invasive' (Robbins, 2004a: 140).

Various social sciences accounts of invasive species have drawn attention to the cultural bias on the categorisations that underlay biosecurity programs and expert knowledge, demanding a more pragmatic damage assessment which is not only based on supposedly straightforward ecological categorizations (Chew, 2015; Davis et al., 2011; Ernwein and Fall, 2015; Kull, 2018; Warren, 2007). For example, classifying species as either 'native' or 'alien' is one of the organising principles of conservation. Still, the validity of this dualism has been questioned based on, among others, the 'ethical disjunction between the promotion of a multicultural human society and the persecution of "foreign" species' (Warren, 2007: 427). In other words, establishing plants' categories based on origin resonates with questions of national identity and exclusion of Others (Alderman, 2004; Foster and Sandberg, 2004; Groening and Wolschke-Bulmahn, 2003; Olwig, 2003, but see Mastnak et al., 2014, for situating natives as the displaced plants from the colonial era). Hence, the calls for widening our temporal perspectives to accept the new socio-natures, and maybe a post-wild world (Collard et al., 2015; Marris, 2013).

The application of instrumental and institutional rationality by the state apparatus to certain species produces 'a scalar jump from weeds as a contextual, field-based relational perception by people-in-landscapes, to "Weeds-with-a-capital-W" as a powerful and bureaucratic category' (Kull and Rangan, 2015: 491). In Australia, species become 'WoNS' (currently 32 listed on the Australian 'Weeds of National Significance'). There are 36 species listed in the UK whose import, breeding, or transportation are regulated by the state. These are not isolated cases: from the 19th century, as part of the (agri)biopolitical effort (Hetherington, 2020b), the state deploys techniques, technologies and discourses to assure invasive species are eradicated or controlled, usually through biosecurity programs that work on public health, agricultural production and borders (Atchison and Head, 2013; Barker, 2008; Barker and Francis, 2021; Hinchliffe and Bingham, 2008). Scientists develop national invasive species databases and complex weed risk assessment models. One discovery of weed control officials patrolling borders and fields can lead to 'aircraft surveillance, ministerial briefings, DNA profiling, herbarium collections, media releases, preparation of management plans, and monitoring for the next twenty-plus years' (Lloyd and Vinnicombe, 2010, cited in Atchison and Head, 2013: 958). Yet, homeowners can 'perform weeds' very differently when adopting biosecurity measures in their gardens (Doody et al., 2014, see also Head and Muir, 2004; Qvenild et al., 2014).

2 Weeds in private gardens

Human-plant scholars have particularly unpacked the role of *planty agencies* (Head et al., 2012) in the context of private gardens (Bhatti, 2006; Hitchings, 2003; Longhurst, 2006; Power, 2005; Robbins, 2007; Sander-Regier, 2009), often with ethnographic approaches in which people demonstrate everyday embodied interactions with plants and weeds. From gardeners' narratives, we know that 'plants help establish, create and reaffirm people's hopes, needs and desires, for example, for beautiful, tidy, or political garden and the sense of place they associated with (….) It is in the midst of this dynamic relationship that the practice of weeding is undertaken' (Doody et al., 2014: 127).

The harmonious idea of people and plants working together to produce gardens (Bhatti, 2006; Hitchings, 2003) can be disrupted when accounting for how weeds can challenge, disrupt and unsettle people's visions and plans for their gardens (Power, 2005). Weeding is also a social process, requiring considerable mobilisation and investment of human labour (Head and Muir, 2004; Sander-Regier, 2009). Weeds are constantly experienced by gardeners, creating dilemmas and forcing material practices that often confront established rules while troubling citizens for having to choose how to deal with them (Doody et al., 2014; Head and Muir, 2004; Qvenild et al., 2014; Robbins, 2007). The intimate relation of gardeners with weeds leads to an appreciation for weeds' fluidity, beauty, or humour, questioning a clear-cut definition of weeds as undesirable (Doody et al., 2014; Sander-Regier, 2009).

A more structural view approaches the political and socio-economic dynamics shaping human-weeds relations in American backyards (Robbins, 2007). For example, Bormann et al. (2001) and Robbins and Sharp (2009) point at how the chemical industry played an essential role in the development of the cultural ideal of a perfect 'clean' lawn and creating demand for herbicides and other products. Thus, garden weeds are also the result of political-economic conditions under which that aesthetic is produced and promulgated. Weeding gardens is not only an activity that unites homeowners with their gardens but also a political act linked to the global agri-food industry (Robbins, 2007). In this regard, whether to weed or not to weed emerge as the central issue of anti-lawn, anti-(urban) monoculture movements in the Western world (Robbins and Sharp, 2003).

Beyond urban and suburban private gardens, weeds also inhabit gardens in urbanising rural environments. For rural "amenity migrants" (non-professional farmers), interacting with weeds is an important part of their learning process towards environmental stewardship (Cooke and Lane, 2015; Gill, 2014). Weeds also emphasise the need for collective action and trust among this population, which might be especially self-interested when securing ecological qualities on their lands (Cooke and Lane, 2015; Graham, 2014). In turn, non-farming rural migrants, performing land management practices (e.g. weed management) in their properties, shape rural ecologies in different ways. First, the fragmentation of the once agricultural space into smaller parcels can complicate invasive species' or agricultural weeds' control (Klepeis et al., 2009). Second, rural newcomers may be less familiar with ecological management, less aware of local weed species, and have less experience in practical land management tasks such as weeding (Cooke and Lane, 2015; Curry et al., 2001).

3 Weeds in the urban and peri-urban 'green' management

A recent post-humanism lens on urban environments has focused on how 'the vegetal' adds new perspectives to the politics of cities and urbanisation (Gandy, 2013, 2019; Gandy and Jasper, 2019a; Hinchliffe et al., 2005; Hinchliffe and Whatmore, 2006; Tzaninis et al., 2020). Such lens acknowledges that urban vegetal life is entangled to diverse dimensions of urban governance, such as municipal labour (Ernwein, 2020; Heynen et al., 2007; Krinsky and Simonet, 2017; Smith, 2020), class-based landscape relationships (Foster, 2005; Patrick, 2014), or citizens' participation broadly (Ernwein and Matthey, 2019; Foster and Sandberg, 2004). Part of this 'vegetal' refers to spontaneous or weedy vegetation.

In the modern urbanisation era, the making of cleaner, healthier and safer cities to expand urban life implied combating weeds. City dwellers and officials

often link weeds to infectious disease, pests, illegal dumping, violent criminals or urban infrastructure deterioration (Falck, 2016; Robbins, 2007), suggesting that 'the significance of weeds in cities is not what they do but, rather what they represent' (Brownlow, 2006: 242). Urban weeds are often ecologies of neglect and disinvestment linked to uneven urban development: the production of vacant land in disinvested areas favours the spread of weeds, which in turn, might shape further disinvestment by producing undesirable aesthetics and imaginaries (Brownlow, 2006; Draus and Roddy, 2018; Falck, 2016). Accordingly, there are policies oriented to weeds' control, such as the 'weed laws' in the U.S., which have regulated the tolerable existence of unwanted plants since the 19th century (Rappaport, 1992; Robbins, 2007; Robbins and Sharp, 2003). However, weeds mean different things to different people, producing conflicts around their management in the public space. Moreover, not all spontaneous plants are considered equally attractive as some might be welcomed while others get displaced (Foster, 2005; Foster and Sandberg, 2004; Patrick, 2014).

In the new institutional turn towards urban green infrastructures and nature-based solutions (Garcia-Lamarca et al., 2019; Kotsila et al., 2020; Wachsmuth and Angelo, 2018), weeds are a conflicted actor. Weeds may be both a desired and planned element in urban nature interventions (Pellegrini and Baudry, 2014) and the target of environmental management directed to exterminate them, often with toxic chemicals (Blanchoud et al., 2004; Gutleben, 2020; Pralle, 2006; Wallace et al., 2016). Urban weeds opened up a controversial debate in 2015 when many municipal governments around the globe discussed the banning of the herbicide glyphosate after its categorisation as possibly carcinogenic by the International Agency for Research on Cancer (Smyth, 2017; Wylie, 2015).

Weeds' presence also serves 'as a portal into alternative interpretations of urban nature' (Gandy and Jasper, 2019b: 6). One of the first sites of studying urban weeds were the bomb sites in the post-war era, shifting the cultural and political significance of urban wastelands (Lachmund, 2003). Cities' histories and global connections are reflected in the urban flora (Sukopp, 2003). For example, as industrialisation advanced and cities grew, the warmer urban microclimatic conditions attracted Mediterranean plants to colder regions (Stoetzer, 2018; Sukopp, 2008). More recently, spontaneous plants are being integrated into parks' design, creating safe havens for biodiversity, reducing municipal gardening budget while providing new types of 'ecological aesthetics' appealing to the upper-classes (Ernwein, 2020; Foster, 2005; Gandy, 2013; Kowarik, 2018; Weber et al., 2014). These newly desired urban ecologies are shaped by certain spatial practices, such as the recently reinvigorated urban foraging (Nyman, 2019; Paddeu, 2019; Pellegrini and Baudry, 2014; Poe et al., 2014), off-leash dog walking (Foster and Sandberg, 2004), or the rise of community gardens (Cabral et al., 2017; Schmelzkopf, 1995; Tornaghi, 2014).

The particular socio-natures of peri-urban areas make weed management a complex endeavour (McLaren et al., 2016). These are patchy and dynamic landscapes in the fringes of the urban and suburban fabric, often enclosing or near wild areas and where weeds find bare or underdeveloped spaces to colonise (Casella and Vurro, 2013; Grella et al., 2018). Here, the governance of environmental amenities, such as green belts or natural parks, overlaps with recreation, tourism, farming, or industry. Yet, inhabitants of these diverse areas (e.g. farmers, ranchers and suburban dwellers) might find common ground in their fear of weeds but disagree in weed management strategies (Klepeis and Gill, 2016; but see Davis and Carter, 2014).

To summarise, we have reviewed how 'humans and weeds go together' (Kull and Rangan, 2015: 497) in national biosecurity plans, private gardens, and the management of urban and peri-urban green spaces. Yet, there is at least one more arena where weeds' agency becomes perceptible and capable of affecting human activities and probably in the most direct way: agricultural fields. Weeds, a broad plant categorisation of ubiquitous presence, compete with crops for water, nutrients, soil and sunlight. This competition is at the heart of a massive mobilisation of human effort on agriculture. The next section develops a vegetal political ecology of weeds and their worldmaking capabilities: how weeds' more-than-human natures affect modern industrial agriculture.

IV Vegetal political ecology of weeds in industrial agriculture

In this section, we explore how weeds condition the modern agri-food paradigm (FitzSimmons, 1986; Goodman et al., 1987; Mitchell, 2012; Weis, 2007) defined as 'the group of businesses, farmers, and institutions focused on maximising agricultural output using industrial methods and logic' (Gray and Gibson, 2013: 86). We consider industrial agriculture as a dynamic network, composed of a 'heterogenous mix of human and non-human components' (Gray and Gibson, 2013: 87), a system, we shall argue, is irremediably shaped by the unique capacities of weeds. Throughout the section, we highlight how three expressions of weediness (i.e. reproduction, dormancy and adaptation capabilities) conditioned the 'industrial agricultural network' by shaping the broader web in which weeds and agricultural farming (farming hereinafter) are embedded.

1 Weeds on farms

In agricultural fields, shared resources such as light, water and nutrients are captured prominently by weeds, which tend to have a negative impact on the physical yield of the crop. They also interfere with maintenance and harvest operations. Moreover, weeds might reduce the quality of the produce, for instance, by producing undesirable substances that mix with harvested cereal. The presence of weeds creates problems in fresh vegetable production, in which produce homogeneity is a requirement: weeds disrupt the uniformity of crops and can change crop's standardised aesthetics (lettuce grows tall rather than wide if competing for light with high weeds). Weeds can also host crop pests and pathogens, attracting vertebrates (e.g. rodents, birds) and invertebrates (e.g. insects) predators. Weed seeds are a source of nitrogen and carbon, which stimulate detrimental bacteria and fungi. Moreover, a bad weed invasion not only decreases crop yield and increases weeding costs, but it might also even reduce land values for decades (as no one would rent a field infested with weeds) (Norsworthy et al., 2012).

Consequently, weeds are crucial in farms' economy, as humans mobilise their efforts to secure crops' growth. Much of agricultural labour is dedicated to weeding, and it was even more in the past: 'Before the onset of chemical control for weeds, most of the work on the farm [in summer] was hoeing (…) Without mechanisation, the size of a farmer's holding and yield was determined by how well (and how fast) a family could weed its land' (Ziska and Dukes, 2011: 1). Zimdahl (2018) argues that more human labour may be expended on weeding than on any other human enterprise. Moreover, farmers plan many farming operations to help crops to get ahead of weeds. Accordingly, weediness affects how farmers choose which crops to grow and when (e.g. deciding not to plant carrots in the summer due to weed pressure) or which farming practices to adopt (e.g. fertilisation or crop sequence). This might ultimately shape farmers' identities (Gray and Gibson, 2013).

In organic farming, weeds are one of the top constraints to pesticide-free production (Liebman and Davis, 2015; Marshall et al., 2003; Müller, 2020). Organic fields tend to have more weed seeds on the soil, although organic growers spend more money on weed control than any other crop input (Albrecht, 2005; Graziani et al., 2012). Some organic farmers integrate particular weeds on their fields' margins or even between cultivation beds. This practice reduces labour while also taking advantage of the beneficial qualities of (certain) weeds. For example, weeds' roots bind the soil together, avoiding erosion. Weeds can increase fertility in different ways (e.g. weeds with deep roots take nutrients from deeper in the ground, making them available on the plant surface), and they are used to attract auxiliary fauna, which help prevent some plagues. In addition, weeds might bring important repairing functions to damaged soils (Ducerf, 2010).

Weeds' significant effects at farms irremediably upscale into the broader agri-food system. In the remainder of this section, we analyse three major events (Brice, 2014 after Bastian, 2012) in modern agricultural history where weeds, or weediness, have been particularly crucial in constructing and advancing the industrial agriculture paradigm. These are the chemical treadmill, the advance of GMOs, and the spread of superweeds.

2 The agriculture chemical treadmill

The struggle against weeds is as ancient as crop cultivation (Gasquez et al., 2019; Krahmer, 2016; Timmons, 2005). For many centuries the hand, the digging-stick and the prehistoric hoe were used for that struggle. Until not that time ago, weeds were not seen as a problem necessarily, and weed control was assumed as part of the agricultural routine (Krahmer, 2016; Timmons, 2005). During the early 20th century, organic chemistry (based on elements like copper, sulphur or lead) and later inorganic chemistry started replacing the hoe and the human hand in Western agriculture. Currently, most of the herbicides used in agriculture and related industries are highly selective, differentiating between crops and weeds attending to morphological, physiological or metabolic characteristics, and each of them is best suited for the control of a specific weed associated with a particular crop. Not all these technologies were developed to deal with weeds at first: the 20th-century pesticide revolution emerged with the war industry as many chemicals arising in the war era were available to farmers as cheap side-products (Guthman, 2019; Robbins et al., 2001; Romero, 2016a, 2016b). Towards the end of the 20th century, petrochemical companies produced agrochemicals on a large scale and were widely marketed to households and farmers.

Industrialised agriculture and liberalised food markets, helped by the availability of cheap pesticides and the new agronomic sciences, gave shape to the new modern agriculture paradigm. This paradigm encourages farmers to maximise the frequency of the most profitable crops, leading to less cultivated diversity. Crop selection is based on profit and not on optimal ecological conditions, erasing one of the most ancient weeding techniques, crop rotation, which allows for varying timings and weeding strategies, interfering with the cycle of different types of weeds. (Leighty, 1938; Liebman and Dyck, 1993). This abandonment exacerbated the dependence on mitigation methods. In addition, mechanisation and credit allowed for the expansion of farms to a vast scale. The consequences of the monocropping and intensification are poorer soils, weaker crops unable to compete with weeds, and better conditions for soil and air-borne diseases (Guthman, 2019; Oskam et al., 1998) – creating a 'chemical treadmill' in which an agrochemical establishes the need for another (Clunies-Ross and Hildyard, 2009). While chemistry (pesticides and oil) facilitated weeding in terms of labour, it did not eradicate weeds: weeding methods had to be applied in every field every season, which demanded the design of an intensified and simplified agricultural system that would save labour costs. At the same time, weeds were enhanced by industrial agriculture by intensifying irrigation or activities involving machinery, which favours seed movements. Moreover, some weeds were introduced by industrial agriculture itself: many of the most pernicious weeds were cultivated because of their virtues (e.g. forage crops such as Johnson grassland or kudzu).

The adoption of herbicide technology during the industrial agri-food expansion was accompanied by conceptual changes in weeds' definition and role within the production system. In the mid-20th century, after discovering the herbicide 2,4-D and the development of agricultural services for farmers engaged in commercial crop production, weeds were represented as a problem that ought to be managed by agricultural technicians and a limiting factor for the industrialisation process. In other words, 'weeds are an "enemy" to be defeated in the ongoing effort to dominate nature' (Binimelis et al., 2009: 627, and see (Williams (2020) for how weeds are also discoursively entangled in efforts to dominate agrarian racialized conflicts). Such subjugation is present in the standard terminology for referring to weeds, including words such as 'control', 'eradication', 'fight', 'wipe out', or 'weapon' (Binimelis et al., 2009, see also Atchison and Head, 2013). This rhetoric reminds the war's machine influence in creating the agrochemical industry and, hence, industrial agriculture. The narrative reflects and continuously reconfigures the imaginaries and actual practices around weeds in modern agriculture, forgetting the more symbiotic relations with weeds, also used as food, medicine, or source of minerals (Hall, 2011; Mabey, 2012). Therefore, the chemical treadmill reflects an addiction to weeds' removal (killing them) and creation (categorising them and favouring the conditions to spread). In the next subsection, we untangle how this chemical dependence was intensified with the development of Genetically Modified Organisms (GMOs).

3 The GMOs-glyphosate formula as a weeding method

Glyphosate, the most used herbicide in the world, was patented by Monsanto in 1974. The patent expired in 2000, decreasing its price and favouring its widespread usage. Glyphosate is a non-selective herbicide that plants absorb mostly through foliage and transport to growing points, from where plants are killed. Before GMOs, glyphosate was applied to fields pre-seeding and pre-emergence (3–5 days after seeding, before the crop seeds have germinated). This helped to control weeds at the beginning of the crop life when plants are more vulnerable to competing species.

In the 1990s, GMOs were developed as a method for weeding management. Herbicide-resistant crops, in particular glyphosate-resistant (GR) crops or, commercially, 'Round Up Ready' crops, have been 'one of the most quickly adopted farming technologies in modern history' (Service, 2007: 1114), as it allowed farmers to more efficiently control weeds. Since then, the use of GR crops greatly expanded in the U.S., where crops accounted for 89%, 91% and 94% of cultivated corn, cotton and soya beans in 2020 (Economic Research Service, 2020) and elsewhere (Binimelis et al., 2009; Hetherington, 2020a; McAfee, 2008). Weed scientists considered the GMO-glyphosate formula 'the most effective and inexpensive weed management technology in history' (Duke, 2018: 1027, see also Baylis, 2000; Dill, 2005; Duke and Powles, 2008). As GR crops meant the simplification of weed-control methods (Owen and Zelaya, 2005), farmers' relations with weeds were so simplified that they became 'weed illiterates', forgetting the knowledge around non-chemical methods (Binimelis et al., 2009: 631).

The management of weeds through GR crops caused an important impact on seed production and distribution and, ultimately, on the whole agricultural system (Howard, 2015; Kloppenburg, 1990; Müller, 2006). GR crops allowed agrochemical corporations to expand their market beyond pesticides, taking control of the seed market, and growing vertically. Through weeds' biological traits and by shaping farmers' concern with them, these companies have been able to control the agricultural system and the different alternatives and discourses that might emerge from it, such as no-till farming.

Tillage prepares the soil for seeding by removing weeds established in the previous season while homogenising and oxygenating the soil. However, tillage disturbs soil structure and conditions, encouraging dormant seeds in the seedbank to germinate. No-till is a cultivation method that aims at suppressing weeds' emergence by avoiding soil movement. No-till farming is celebrated as a solution to solve erosion and climate change, as it favours more robust soil structures and does not release soil's naturally-stored carbon. The recent resurgence of this method has reinforced the expansion of the industrial agriculture paradigm, increasing the speed of field preparation (a single herbicide application is faster than two passes of tillage equipment) what favours larger, more intensive farms. There is a timid movement of organic no-till, but most of the no-till farming is practised today by conventional grain farmers. Indeed, the technique remains dependent on herbicides since most no-till farmers use glyphosate in several phases: pre-seeding, post-seeding and even as a pre-harvest desiccant for drying out crops quicker and evenly (Friedrich and Kassam, 2012; Shaner and Beckie, 2014).

The celebration of no-till farming has contributed to institutionally expand the idea of 'living soils' in agriculture (Granjou and Phillips, 2019; Puig De la Bellacasa, 2015), which work to preserve soil biota, including worms and other soil organisms (Müller, 2020). But the technique's current reliance on chemical herbicides makes it very aggressive with those organisms and birds or insects, dependent on aboveground biodiversity. In addition, the farmers and farmworkers who apply the herbicides take on specific health risks. These dilemmas represent the complex imaginaries of agriculture's sustainability that farmers have to navigate (Dentzman, 2018; Gray and Gibson, 2013; Müller, 2020). In the following subsection, we relate how the appearance of glyphosate-resistant weeds might have helped to propel more sustainable weeding practices.

4 Superweeds outsmart herbicidal technologies

As part of the constant adaptation for survival, weeds can develop resistance to herbicides by biological and genetic mechanisms prompted by the regular and repeated application of the same herbicide in one field (Adler, 2011). The widespread use of glyphosate led to the adaptation of several weeds to this substance. The first glyphosate-resistance weed, *Lolium rigidum Gaud*, was found in Australia only four years after introducing glyphosate-resistance GMOs in the country, in 1996. Today, around 40 glyphosate-resistant weeds are spread in 37 countries, affecting 34 different crops (Heap and Duke, 2018). As some weeds become resistant to glyphosate or other herbicides, they take advantage of their favoured position and fill the space left by other weeds, expanding quickly in the fields. Today, millions of acres in the U.S., Argentina or Brazil (top glyphosate users) are affected by what is increasingly known as 'superweeds'.

The widespread adoption of the GMO-glyphosate formula placed 'unprecedented pressure on weeds, creating an ideal environment under which resistant weeds could quickly develop' (Bain et al., 2017: 219). The appearance of superweeds involved weeds' biological traits for adaptation. It was also accompanied by governmental agricultural technicians and retailers of agrochemical products who downplayed herbicide resistance issues and were reluctant to recommend alternative methods (Bonny, 2016; Mortensen et al., 2012). The phenomenon is tightly connected to both the widespread adoption of glyphosate-dependent no-tillage as a promise for sustainability (Mortensen et al., 2012; Soane et al., 2012) and to policies and regulatory systems prone to favour chemical use despite knowledge of associated risks, and which continuously under-enforces pesticides' codes (Galt, 2008; Jansen, 2017; Tosun et al., 2019; Guthman, 2019). In addition, alternatives to the use of herbicides might also be limited by labour availability (Egan, 2014) or pressure from landowners (Norsworthy et al., 2012).

The consequences of superweeds are wide-reaching. They increase the production cost of farmers and decrease their yields (Livingston et al., 2015). Superweeds make herbicide management practices a 'common pool nature' (Shaner and Beckie, 2014: 1330) in which harmful practices of one farmer (by overusing one single herbicide and planting monocrops year after year) affect all growers in the same bioregion. Because of emerging resistance, farmers have to adapt to work differently, and some return to tillage practices as glyphosate and other herbicides turn ineffective. Meanwhile, the response of agrochemical companies has been to combine herbicide-resistant traits to allow for more and varied herbicide applications. On the ground, this means increasing glyphosate doses or using more toxic herbicides (such as Dicamba, 2-4D and others) to kill those superweeds or to pair with GMO seeds (i.e. creating new herbicide-resistant crops). While superweeds might open the market for developing new herbicides, they might have delayed the expansion of other GMO crops such as wheat, which has been expected for decades (Dill, 2005). In a way, they might have inclined the direction of agriculture towards the opposite direction than research was pointing at (Vanloqueren and Baret, 2009).

Experts agree that the expansion of superweeds signals a critical juncture for conventional agriculture (Adler, 2011; Beckie and Hall, 2014; Mortensen et al., 2012; Union of Concerned Scientists, 2013). In other words, it is suggested that 'the most daunting threats to glyphosate's dominance and Roundup sales are not health concerns or lawsuits but weeds themselves' (Cohen, 2019: no page number). As the appearance of glyphosate-resistant weeds was foreseen and avoidable, agrochemical corporations might have lost some credibility. It is expected that some governmental agricultural technicians and regional policies, as they realise that 'managing herbicide-resistant weeds solely with herbicides is doomed to failure' (Beckie and Hall, 2014: 44), set more ecological weed management practices as policy priorities. National policies are moving towards more sustainable practices. Since 2019, Germany and Mexico have announced the phasing out of glyphosate. Austria has approved a partial ban and France has declared to have the same intention. In 2020, the European Commission released Farm to Fork, setting the objective of reducing pesticides use by 50% in 10 years. In the U.S., where pesticide regulation is less strict, the judicial procedures against Monsanto-Bayer (Cohen, 2020) might influence future pesticide policies. For now, in November 2020, the U.S.

Environmental Protection Agency released the draft of a biological evaluation of glyphosate, which confirms the herbicide's negative impacts on endangered species and habitats. Changes such as these ones might contribute in uncertain ways to the shifting geographies of glyphosate production and use (Werner, in press).

To sum up, this vegetal political ecology reveals how agro-industrial weeds are entangled to farmers, chemicals, soil, crops, agri-food companies, governmental agricultural technicians or the state. In the context of industrial agriculture, these relationships are forced into a complex equilibrium. The vegetal political ecology of agro-industrial weeds untangles how agricultural practices, technologies and regulations adapted to weeds' biological traits and what this means, on a more fundamental level, about the relation between farming and their more-than-human components, unwanted flora in this case. On the one hand, it encourages weeds scientists and agrarian scholars to rethink how weeds have been implicated with agricultural practices and socio-political and economic structures over a long period and across changing contexts. On the other hand, it urges geographers of food and agriculture to acknowledge how food is produced in a subtler form, paying attention to more-than-human actors in the food system.

V The persistent lives of weeds

After having reviewed how weediness relates to border controls, and impact upon the management of urban and peri-urban green spaces, private gardens and industrial agriculture, this vegetal political ecology of weeds may open up three interrelated threads of discussion: 1) How weeds shape the understanding of human-plants relationships; 2) The centrality of weeds in agriculture; 3) The move towards a more-than-human geography in agriculture.

1 How weeds can shape our understanding of human-plant relationships

Human-plants scholarship has pointed out that some of 'the most embodied garden encounters come between humans and plants they are trying to get rid of, the plants that will not behave themselves' (Head and Atchison, 2009 after Zagorski et al., 2004). Is our relationship with weeds different from trees, crops or ornamental flowers? And if so, how? Relational accounts tend to represent the more-than-human as a constructive or pliant agent, almost domesticated. Here, plants allow for food, feed and fibre, for human settlements and state-making processes; trees create place-making and contribute to affective and emotional responses from humans; technologies co-construct our society at the same time that we develop technologies, and so on.

On the contrary, weeds tend to trouble human lives. Weeds grow faster, produce more seeds and spread farther than other plants – and in that sense, weeds' material performances also reflect the entangled relations among plant species (Tsing et al., 2020). Their fast reproduction and growth allow them to spread (grow, reproduce and grow again) in a single growing season in agricultural sites or places laid bare by fires and floods or occupied by 'local' species. Dormant weed seeds can extend weed infection on fields for decades – echoed in the popular expression '1 year's seeding makes 7 years' weeding' – imposing a particular tempo on farms and elsewhere. It is weeds' materiality, their weediness, that makes them uncooperative, making an analogy with Karen Bakker (2005) approach to water. However, while Bakker talked about water as an 'uncooperative commodity', weeds, differently from other plants, are not commodities. They are not valued, and their unproductive nature is at the heart of their insurgent and disruptive character.

Other troubled relationships with non-human companions have been explained elsewhere, either as pathogens, microbes and viruses (Crosby, 2004; Del Casino, 2018; Guthman, 2019; Paxson, 2008), slugs (Ginn, 2014) or mosquitoes and other insects (Beisel, 2010; Beisel et al., 2013) – creatures that have been defined as stubborn (Marder, 2013), monstrous (Ginn, 2014), or fugitive (Robbins, 2004b). Weeds, and all the species with undomesticated lives, pose ethical, technical, or health barriers to the advance of human social life; they 'shout challenges to stability' (Tsing, 2017: 4). And for that reason, these creatures are at the heart of human-nature relations, and we can learn from them about the constant contradiction embedded in our understanding of and interaction with nature.

We acknowledge these relations are dynamic, heterogeneous and open to change. The valorisation of weeds by emerging urban sustainability approaches (including green infrastructures or nature-based solutions in cities) is an exciting sign, however small, of how weeds got to be seen as co-production agents of urban natures. In other words, weeds' 'feral charisma' (Lorimer, 2007), their wild and chaotic nature might be interpreted as a positive quality. This turn might signify an opening towards a different relationship with weeds, one that might even question the assumption that weeds are always unwanted plants. Critical invasive science is also questioning how plants become weeds and why (Kull, 2018; Warren, 2007). In private gardens, homeowners do not always kill, but they also care for and reproduce invasive plants (Doody et al., 2014; Head and Muir, 2004). Those 'flexible boundaries' reflect our cultural production of wanted and unwanted nature, or as Lorimer put it, that we are 'deciding among multiple biodiversities or multinatural futures' (Lorimer, 2012: 601; Lorimer, 2006). While it is beyond the scope of this article, we acknowledge that there are diverse ways that people from western and non-western cultures relate to wild plants – many of them so-called weeds – through foraging, medicine, culinary traditions or ecological management. Many of these practices have been erased by historical dynamics of land dispossession, industrialisation or capital accumulation, as well as by power imbalances on discourses over nature that have historically deemed certain practices inferior (Anderson, 2013; Kawa, 2016; Kimmerer, 2020). Many of these exclusionary dynamics are closely related to the development of industrial agriculture that we narrate in the previous section.

Those flexible boundaries manifest in agriculture too. Certain weeds (e.g. nutgrass or *Cyperus rotundus*) can be weeded with harvesting machinery, certain crops become weeds when they grow spontaneously, and many ancient crops have evolved to weeds. In addition, in some forms of organic farming, weeds are favoured and appreciated because of some beneficial properties to the soil and auxiliary fauna. Paradoxically, because of this appreciation and the reluctance to use faster and cheaper chemical methods to eradicate them, farmers embrace more complex relations with weeds (Liebman and Dyck, 1993; Müller, 2006). This troubled relation, rooted in weeds' material performances, might be at the heart of the gap between conventional and organic agriculture (notwithstanding the different approaches within organic farming, not to mention agroecology), even if this aspect is recurrently ignored by Alternative Food Networks and food systems scholars. This point brings us to the second thread of discussion: the centrality of weeds in agriculture.

2 The centrality of weeds in agriculture

In this paper, we have paid attention to agro-industrial weeds, moving beyond the shared vision of weeds as disruptors of landscape ecologies and actors in biosecurity efforts. Instead, weeds on farms are very often indigenous species inhabiting human-disturbed farmland. Far from national biosecurity plans, lists and categories, weeds on farms are controlled by a quotidian yet planned strategy by farmers and farmworkers who incorporate weed management in their daily or weekly routine and within the rest of farming operations. Yet, this intimate farmer-weed relation is tied to significant political-economic and agrarian consequences. And maybe for that reason, weeds on farms are not outside the control of the state, that occurs, for example, in the routine monitoring of governmental agricultural technicians advising weeding techniques. While we have focused here on the entanglements of agro-industrial weeds with the political economy of industrial agriculture, more work is needed to understand the intimate human-plant relationship occurring in fields (what Brice, 2014 or Fleming, 2017 do at vineyards and orchards).

We have untangled how weeds maintain a dialectical relationship with modern agriculture: while apparently insurgent as they disrupt agricultural practices, weeds have decisively contributed to the construction of the industrialised agricultural system as we know it. Weeds became a bottleneck to the expansion of industrial agriculture in the 20th century. Still, this limitation boosted industrial agriculture: The persistent lives of weeds gave agrochemical players a steady control over the agricultural system as they were able to advance the use of monocrops, herbicides or GMOs, which were to become the pillars of the industrial agriculture paradigm. At the same time, weeds also resisted, and continue to resist,

the biological homogeneity of agricultural fields those agro-chemical players seek. That is, despite the disciplining of inconvenient flora favoured and expanded by industrialised agriculture, intensive agricultural practices have been unable to stifle weeds' ability to affect change. In other words, unwanted plants keep growing and keep having to be weeded, and they continue causing economic losses and environmental trouble.

As superweeds mutate quickly to adapt to herbicides, they put into question the most extended and taken-for-granted farming practices (such as chemical weeding, GR crops or conventional no-till farming). Indeed, not only adaptation but weediness broadly constantly challenges four quintessential characteristics of industrial agriculture: homogeneity, predictability, calculability and control (Haraway, 2015). Therefore, as the double role attributed to trees' graftability (Fleming, 2017) or grains' traceability (Scott, 2000, 2017), and other non-humans (Robbins, 2004b: 234–235), weeds' persistent reproduction contributes to both undermining and supporting the complex, power-laden and multi-scalar networks of relations that constitute today's industrial agriculture.

3 More-than-human geography in agriculture

Last, the paper shows the possibilities that more-than-human geography opens in the field of agriculture. The recent 'following' plants type of study see crops and food – strawberries (Guthman, 2019), potatoes (Nally and Kearns, 2020), or almonds (Reisman, 2020) – as sites and sources of human struggles embedded in the economics and politics of agri-food systems and other dimensions of human life. These sorts of studies have opened the space for integrating more material approaches in the social sciences studies of agriculture, still scarce despite having being claimed to be studied for so long (Goodman, 2001; Marsden, 2000; Watts and Scales, 2015).

So far, even when focused on pesticides or GMOs, critical geography and political ecology barely touch upon weeds as an entangled actor (with some exceptions, such as Bain et al., 2017; Binimelis et al., 2009; Dentzman, 2018; Müller, 2020). And yet, current analysis for just, diverse and sustainable agri-food systems tend to exclude more-than-human actors (e.g. Koretskaya and Feola, 2020; Sonnino and Marsden, 2006; Moragues-Faus et al., 2020; Thompson and Scoones, 2009). However, there is no place like agriculture where plants' capacities are more explicit, where humans' reliance on them is more apparent, and where 'plants contend with stronger flows of power' (Fleming, 2017: 27). Since agriculture and agrarian economies are so fundamentally tied to material conditions (those of seeds, crops, soils, weeds) (Mann and Dickinson, 1978), a sensitivity to learning to perceive non-humans' capacities to affect human bodies and activities becomes more than appropriate for teasing out agricultural relations, dynamics and tensions, as Brice (2014) has carefully shown. Moreover, a closer engagement with ecological processes in agriculture can be particularly insightful for understanding lived experiences, motivations and problems of those who are more tied to such ecology on a day-to-day basis, that is, farmers and farmworkers.

In that sense, vegetal political ecology reveals as an excellent framework for the understanding of more-than-human interactions in agriculture. The power of the framework comes from the three actions it tries to connect: 1) attending to particular plants' capacities – such as fruit ripening, trees' graftability, or weeds' dispersal – and the intimate human-plant relations they enact; 2) connecting these with different human practices (weather watching, maturity testing, weeding or tilling); and 3) linking plants' characteristics and human practices to a broader system of resource and environmental politics. Vegetal political ecology becomes a ground on which political consideration of human-plant relations might challenge dominant modes of thinking and practicing agriculture.

VI Conclusion

So far, in-depth considerations of the political ecology of weeds have mostly centred around the ways weeds are managed or critiques of how these are produced by classifications (e.g. Atchison and Head, 2013; Bain et al., 2017; Kull and Rangan, 2015). We develop a vegetal political ecology of weeds by expanding on these political ecology perspectives and attuning to weeds' actual ecology. We do so by paying attention to how weeds' unique

capacities (reproduction, dormancy and adaptation to external conditions) interrupt and reconfigure different dynamics and processes, such as urban development, biosecurity plans, backyard gardening, and especially, farming.

In particular, we have untangled how weeds' active materialities have been significantly influential in advancing the industrial agriculture paradigm by enacting key events such as the chemical treadmill, the consolidation of the GMOs-glyphosate strategy and the recent expansion of superweeds. At the same time, weeds continue challenging this same paradigm by their ability to multiply, wait and adapt. While critical geography accounts of food and agriculture have paid little attention to the role of weeds on farms, in this article, we place weeds as an actor interacting with GMOs, agrochemicals, soil, farmers, in such a way that, as weeds get shaped by agriculture, agriculture is re-constituted – if partly – by weeds. This vegetal political ecology makes clear that the task of making agriculture more environmentally and socially sustainable entails changing the way we deal with weeds, as well as rethinking what weeds mean to us.

To sum up, weeds and humans chase each other in a biologically intimate relationship that is ubiquitous and persistent. This vegetal political ecology of weeds responds to pressing needs to re-construct our entanglements with non-human actors. We do so by highlighting an undisciplined agency that has often been understudied in geography research. The disruptive human-weeds relation is revelatory from a relational perspective for providing a way to unpack apparent convivialities and stabilities while opening more loose understandings of relationality. It also calls attention to the barriers that unwanted plants impose and the powerful interests that try to overcome those either by changing or controlling weeds' ecological characteristics of the institutional systems that govern them.

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