

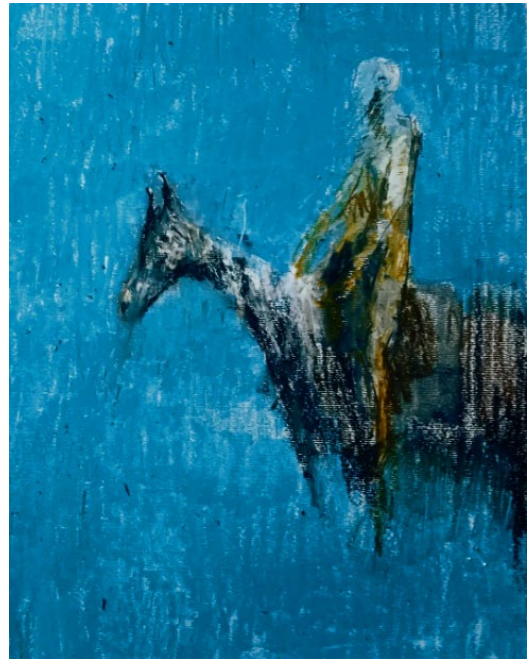
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NEGOTIATING DOMESTICATION: REVISITING PLANT AGENCY WITH AGRICULTURAL PESTICIDES

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ABSTRACT: NEGOTIATING DOMESTICATION: REVISITING PLANT AGENCY WITH AGRICULTURAL PESTICIDES

This paper explores the role of crop plants as agents in anthropogenic environments marked by both pesticide contamination and drought. Drawing from plant physiology, ecotoxicology, and multispecies ethnography, we argue that plants are not passive recipients of human agricultural intervention, but active agents capable of biochemical responses, adaptation, and ecological remediation. Also, we trace how pesticides, while intended to enhance crop productivity, have cascading and often harmful effects on ecosystems, contributing to biomagnification and long-term toxicity. Yet, these same substances trigger plant detoxification mechanisms that form the basis for phytoremediation. We highlight the agency of crop plants under pesticide stress and propose a reframing of domestication as a bidirectional relationship between humans and crops, exemplified through phytoremediation processes.



1. Introduction

Rachel Carson's *Silent Spring*, published in 1962 and denouncing the environmental harm caused by DDT use since World War II, has contributed to more than 60 years of reflection on agricultural technologies and on the relationship between humans and their environment¹. Synthetic pesticides remain a topic of crucial contemporary relevance across disciplines, as their usage has increased in the global food production complex, and synthetic chemical input into the environment has grown faster in the last

¹ R. Carson, *Silent Spring* (1962), Mariner Books Classics, New York 2022.

50 years than any other single driver of global environmental change, including greenhouse gas emissions².

This contribution offers a take on the agency of plants in anthropogenic conditions. It asks the question: which kinds of agency emerge if we take the agency of crop plants seriously³ in their interactions with some pesticides and within the relationships of domestication they are a part of? The paper describes how crop plants dwell within anthropogenic environments, in which agricultural pesticides play a key role as technologies of domestication, i.e. in shaping the conditions of existence of plants according to human designs⁴. It takes on plant agency in a «postnatural world»⁵ and in «a Plantationocene»⁶, in the challenging setting that toxicity presents for nonhuman agencies. Following Anna Tsing's invitations to engage with relationships of domestication⁷ and with the anthropogenic landscapes of the contemporary⁸, the paper endeavours to highlight the unique agency of crop plants – even in their domesticated condition. Indeed, it engages with anthropological and biological literature on domestication⁹; inspired by multispecies ethnographies¹⁰, and

² E.S. Bernhardt, E.J. Rosi, & M.O. Gessner, *Synthetic chemicals as agents of global change*, in «Frontiers in Ecology and the Environment», XV, 2, 2017, pp. 84-90.

³ M. Candea, *Endo/Exo*, in «Common Knowledge», XVII, 1, 2011, pp. 146-150.

⁴ T. Ingold, *Growing plants and raising animals: an anthropological perspective on domestication*. In D. R. Harris (ed.) *The Origins and Spread of Agriculture and Pastoralism in Eurasia*, Smithsonian Institution Press, Washington D.C. 1996, pp. 12-24, pp. 12-24, p. 21.

⁵ T. van Dooren, E. Kirksey, & U. Münster, *Multispecies studies: cultivating arts of attentiveness*, in «Environmental Humanities», VIII, 1, 2016, pp. 1-23, p. 3.

⁶ M. Barua *Plantationocene: A Vegetal Geography*, in «Annals of the American Association of Geographers», CXIII, 1, 2023, pp. 13-29.

⁷ A.L. Tsing, *Provocation: Nine Provocations for the Study of Domestication*. In H.A. Swanson, M.E. Lien, & G.B. Ween (eds.), *Domestication Gone Wild: Politics and Practices of Multispecies Relations*, Duke University Press, Durham 2018, pp. 231-251.

⁸ A.L. Tsing, *On Anthropogenic Landscapes*, in «A bestiary of the Anthropocene», ed. N. Nova. Onomatopoe: disnovation.org, 2021. Accessed September 25, 2021.

⁹ M.E. Lien, H.A. Swanson, & B.W. Gro, *Introduction. Naming the Beast-Exploring the Otherwise*. In H.A. Swanson, M.E. Lien, & G.B. Ween, (eds.), *Domestication*

vegetal geography¹¹, we describe how plants sense their environment and actively modify their behaviour through phenotypic plasticity¹². Far from depoliticising synthetic pesticide use, we note the devastating effects of synthetic products on ecosystemic equilibria. Against this background, however, we aim to highlight how skilled plants are at filtering and bypassing the toxic effects of pesticides. To do so, we 1) review insights from biology exemplifying the unique types agency of plants under stress, as exemplified by drought¹³, and specifically under stress caused by synthetic pesticides¹⁴; 2) describe the behaviour of plants as organisers of multispecies relationships that can provide potential alternatives to the toxicity of some of the current agricultural practices. Through a dialogue between anthropology and biology, we build a nuanced understanding of the agency of crop plants. We situate the interaction between crops and pesticides within an understanding of domestication that does not imply human mastery over nature, rather mutual influence between species, where nonhuman agencies can always be found. Finally, we aim to show how the very active qualities of plants

Gone Wild: Politics and Practices of Multispecies Relations, Duke University Press, Durham 2018, pp 1-32.

¹⁰ E. Kohn, *How Forests Think: Toward an Anthropology beyond the Human*, University of California Press, Berkeley 2013; A.L. Tsing, *The Mushroom at the End of the World: On the Possibility of Life in Capitalist Ruins*, Princeton University Press, Princeton 2015¹; W. Ellis, *Plant knowledge: transfers, shaping and states in plant practices*, in «Anthropology Southern Africa», XLI, 2, 2018, pp. 80-91.

¹¹ J. Brice, *Attending to grape vines: perceptual practices, plant agency and multiple temporalities in Australian viticulture*, in «Social & Cultural Geography», XV, 8, 2014, pp. 942-965; A.M. Lawrence, *Listening to plants: Conversations between critical plant studies and vegetal geography*, in «Progress in Human Geography», XLVI, 2, 2022, pp. 629-651.

¹² S.E. Sultan, *Phenotypic plasticity and the neo-Darwinian legacy*, in «Evolutionary Trends in Plants», VI, 1992, pp. 61-71.

¹³ S. Gilroy, & T. Trewavas, *Agency, teleonomy and signal transduction in plant systems*, in «Biological Journal of the Linnean Society», CXXXIX, 4, 2023, pp. 514-529, p. 516.

¹⁴ T. Singh, & D.K. Singh, *Phytoremediation of organochlorine pesticides: Concept, method, and recent developments*, in «International Journal of Phytoremediation», IXX, 9, 2017, pp. 834-843.

make them protagonists in multispecies alliances and potential nature-based solutions.

2. *The agency of plants*

For a long time, Western understandings of biological life followed the Aristotelian classification, which relegated plants to a lower status compared to humans and animals; specifically, plants were considered inferior because they were thought to be immobile¹⁵. An array of different disciplines has contributed, especially over the last two decades, to shedding light on this simplification in favour of a profound attention to the specificities of plants, and to their multiple, complex, and unique forms of agency. This attention can be first traced in the layered and diverse kin of multispecies studies¹⁶, which also follows Anna Tsing's calls for noticing nonhuman forms of life and for being attentive to non-scientific ways of engaging with them¹⁷. These multispecies ethnographies¹⁸ have emerged since the 2000s as multidisciplinary projects devoted to highlighting the interconnectedness between humans and «the lives of fungi, microorganisms, animals, and plants»¹⁹. Anthropology has helped in giving salience to relational, non-Western conceptions of nature, and to Indigenous people's knowledge of plants²⁰. In the contemporary, postnatural world, the contribution of anthropology has rather been to pay close attention to what plants actually *do*,

¹⁵ M. Hall, *Plants as persons: A philosophical botany*, State University of New York Press, New York 2011.

¹⁶ D. Haraway, *Staying with the Trouble: Making Kin in the Chthulucene*, Duke University Press, Durham 2016.

¹⁷ A.L. Tsing, *Arts of Inclusion, or, How to Love a Mushroom*, in «Australian Humanities Review», L, 5, 2011, pp. 5-22.

¹⁸ S.E. Kirksey, & S. Helmreich, *The Emergence of Multispecies Ethnography*, in «Cultural Anthropology», XXV, 4, 2010, pp. 545-76.

¹⁹ T. van Dooren, E. Kirksey, & U. Münster, *Multispecies studies: cultivating arts of attentiveness*, cit., p. 3.

²⁰ E. Kohn, *How Forests Think...*, cit.; R.W. Kimmerer, *Indigenous Wisdom, Scientific Knowledge*, Milkweed Editions, Minneapolis 2015.

to their unique ways of understanding their environment and communicating with other species²¹.

Recent theories in evolutionary biology and physiology define the agency of organisms as the capacity of agents to «act autonomously to direct their own behaviour to achieve both external and internal goals or norms while in continuous long term interaction with the real-world environment»²². Specifically, plants demonstrate their agency through phenotypic plasticity, or the capacity to change their phenotype²³. Anthropologists have problematised and conceptualised what it means to take these forms of plant agency seriously²⁴, asking «what it is that plants do, what and how they know and sense, and how they recognise and associate with their kin»²⁵. To build «plant-centred methodologies»²⁶ means to listen to plants, to enter into an affective relation with them²⁷. This has been explored in two different ways: one involves attending to «what people do with plants as well as what plant practitioners think plants actually do»²⁸. For instance, William Ellis has observed how Rastafarians in South Africa (Western Cape; Namaqualand) understand plant knowledge as something directly granted by plants themselves, received through focusing the senses on their active

²¹ E. Kohn, *How Forests Think...*, cit.

²² S. Gilroy, & T. Trewavas, *Agency, teleonomy ...*, cit., p. 516. See also R.D. Beer, *Intelligence as adaptive behaviour*, Academic Press, San Diego 1990, and D.M. Walsh, *Organisms, agency and evolution*, Cambridge University Press, Cambridge 2015.

²³ S. E. Sultan, 1992. *Phenotypic plasticity and the neo-Darwinian legacy*, in «Evolutionary Trends in Plants», VI, 1992, pp. 61-71; quoted in S. Gilroy, T. Trewavas, *Agency, teleonomy ...*, cit, p. 516.

²⁴ M.Candea, *Endo/Exo*, cit.

²⁵ D. Gibson & W. Ellis, *Human and plant interfaces: relationality, knowledge and practices*, in «Anthropology Southern Africa», XLI, 2, 2018, p. 76.

²⁶ D. Gibson, *Towards plant-centred methodologies in anthropology*, in «Anthropology Southern Africa», XLI, 2, 2018, pp. 92-103.

²⁷ T. van Dooren, *Care: Living Lexicon for the Environmental Humanities*, in «Environmental Humanities», V, 2014, pp. 291-294.

²⁸ D. Gibson & W. Ellis, *Human and plant interfaces: relationality, knowledge and practices*, cit., p. 76.

communication²⁹; Julie Soleil Archambault has similarly endeavoured to take seriously the love that gardeners in Mozambique have for – and receive from – plants³⁰. On the other hand, scholars in the emerging field of vegetal geography and its cousin critical plant studies have endeavoured to explore the possibilities of listening to plants themselves, to their environmental perceptions and communications³¹. Jeremy Brice has reflected on how grape vines in Australian viticulture demonstrate their own agency engaging with farmers' practices³². Other more conceptual works have reflected on the distinctive agencies of plants, highlighting their unique and «particular materiality; mobility (without human intervention); sensing and communicating; and taking shape as flexible bodies»³³. In anthropology, the most salient examples remain Eduardo Kohn's ethnography of vegetal semiotics in the Amazon³⁴, Anna Tsing's multi-sited ethnography of *Tricholoma matsutake* mushroom's entanglements with humans, trees, and late capitalism³⁵, as well as Tsing's current project on attuning to mycorrhiza's form as their mode of existence³⁶. Following these perspectives, we endeavour to highlight forms of plant agency under conditions of stress, with the example of

²⁹ W. Ellis, *Plant knowledge: transfers, shaping and states in plant practices*, cit.

³⁰ J.S. Archambault, *Taking Love Seriously in Human-Plant Relations in Mozambique: Toward an Anthropology of Affective Encounters*, in «Cultural Anthropology», XXI, 2, 2016, pp. 244-271.

³¹ A.M. Lawrence, *Listening to plants: Conversations between critical plant studies and vegetal geography*, in «Progress in Human Geography», XLVI, 2, 2022, pp. 629-651.

³² J. Brice, *Attending to grape vines: perceptual practices, plant agency and multiple temporalities in Australian viticulture*, cit.

³³ L. Head, J. Atchison, & C. Phillips, *The distinctive capacities of plants: re-thinking difference via invasive species*, in «Transactions of the Institute of British Geographers», XL, 2015, pp. 399-413, p. 410.

³⁴ E. Kohn, *How Forests Think...*, cit.

³⁵ A.L. Tsing, *The Mushroom at the End of the World...*, cit.

³⁶ A.L. Tsing, *Attunement: Form in motion. Special Contribution. Curatorium* (<https://www.curatorium.au/taja-journal/form-content/attunement-form-in-motion>), 2024.

drought-induced stress, as a preamble for our discussion of crop plants' forms of agency under pesticide-related stress.

3. *Plants and Drought Stress*

Higher plants are sessile organisms, rooted in one position and apparently without movement. Trewavas poses the question, «What is plant behaviour?» and «How can plant behaviour be described?»³⁷. These questions are closely linked to the statement by Simon Gilroy and Tony Trewavas³⁸ that our expectations about behavioural responses are defined through the observation of movement.

We illustrate plant behaviour and movement through their responses to stress, with a particular focus on drought stress. To do this, we highlight the cause-and-effect relationships described by Gilroy and Trewavas in their statement that «plasticity indicates agency»³⁹. As we have introduced, plants direct their own behaviour, acting as agents through phenotypic plasticity, which is their ability to change physiology, morphology, and phenology to adapt or tolerate stresses⁴⁰. Gilroy and Trewavas summarize phenotypic plasticity in morphological changes, allocational responses, anatomical variation and numbers of tissue cells and their behaviour⁴¹.

Stress – abiotic or biotic – represents a negative interaction affecting an organism, where its ability to tolerate and/or adapt determines its chances of survival⁴². The complexity of the stimuli that plants must overcome is significant, and they must be prepared to face a wide range of stress combinations. As defined

³⁷ T. Trewavas, *What is plant behaviour?*, in «Plant, Cell and Environment», XXXII, 2009, pp. 606–616.

³⁸ S. Gilroy, T. Trewavas, *Agency, teleonomy ...*, cit.

³⁹ S. Gilroy, T. Trewavas, *Agency, teleonomy ...*, cit., p. 516.

⁴⁰ L. Aguirrezabal, S. Bouchier-Combaud, A. Radziejwoski, M. Dausat, S. & C. Granier, *Plasticity to soil water deficit in Arabidopsis thaliana: Dissection of leaf development into underlying growth dynamic and cellular variables reveals invisible phenotypes*, in «Plant, Cell and Environment», XXIX, 12, 2006, pp. 2216–2227.

⁴¹ S. Gilroy, T. Trewavas, *Agency, teleonomy...*, cit.

⁴² G. Cramer, *Abiotic stress & plant responses from the whole vine to the genes*, in «Australian Journal of Grape and Wine Research», XVI, 1, 2010, pp. 86–93.

by Cramer⁴³, the plant responses can depend on the duration of stress (acute or chronic), on single or multiple stresses leading to a crosstalk between pathways, and on the tissue or organ affected by the stress. To cope, they have often developed a sophisticated network of signalling, enabling them to respond with an initial rapid inhibition followed by a tolerance mechanism adapted to the new conditions⁴⁴.

Morphological, physiological and biochemical responses of plants to drought stress is an important text about plant-stress interaction⁴⁵. In it, the authors state that some plants can exhibit morphological, physiological, and biochemical responses to stress, as illustrated by the example of drought. In chronic or emergent dry conditions, the roots struggle to absorb sufficient water, triggering a cascade of effects that ultimately return the plant to its pre-stress state. Cell growth is the most impacted physiological process due to a reduction in turgor pressure. The latter causes – as a morphological response – a reduction in the number of leaves per plant, leaf size and leaf longevity based on the absence of water flow from roots to surrounding elongating cells. In order to face the reduction in turgor pressure, some plants implement a physiological response accumulating organic or inorganic solutes in the cytosol to attract water. The osmotic adjustment actors are proline, sucrose, and soluble carbohydrates allowing water uptake from the soil.

Certainly, there is an interplay between source and sink – root and shoot system – establishing communication and physiological responses activation. Indeed, roots in water-stress conditions

⁴³ G. Cramer, K. Urano, S. Delrot, M. Pezzotti & K. Shinozaki, *Effects of abiotic stress on plants: A systems biology perspective*, in «BMC Plant Biology», XI, 163, 2011.

⁴⁴ A. Skiryecz, & D. Inzé, *More from Less: plant growth under limited water*, in «Current Opinion in Biotechnology», XXI, 2010, pp. 197–203.

⁴⁵ S. Anjum, X. Xie, L. Wang, M. Saleem, C. Man, & W. Lei, *Morphological, physiological and biochemical responses of plants to drought stress*, in «African Journal of Agricultural Research», VI, 9, 2011, pp. 2026–2032.

induce a signal cascade including abscisic acid (ABA), cytokinins, ethylene, malate and others⁴⁶. Basu, Ramegowda, Kumar and Pereira in *Plant adaptation to drought stress*⁴⁷ describe that ABA coordinates responses about stomatal closure causing reduction in water transpiration but also CO₂ entrance limitation, nutrient uptake and altering photosynthesis. Potentially, enhancing leaf shedding, reducing leaf number or leaf size and branching are other adaptations in limiting water loss. Basically, some plants respond by closing the points where water can escape, trying to retain it internally. If this is not sufficient, they then reduce or shed the parts that could lose water and are not essential for their survival.

Anjum explains that stomatal closure helps reduce water loss through transpiration but leads to the accumulation of reactive oxygen species (ROS)⁴⁸. However, plants have actively addressed this issue through two different strategies. ROS include oxygen ions, free radicals and peroxides and they can highly damage plants through protein degradation or DNA fragmentation⁴⁹. ROS are a consequence of stomatal closure and CO₂ limited concentration causing the accumulation of reduced photosynthetic electron transport components that are able to reduce molecular oxygen and produce ROS⁵⁰. Consequently, there is an enzymatic and non-enzymatic defensive system in some plants. The former includes enzymes such as peroxidase, catalase or superoxide dismutase and the latter is based on maintaining the integrity of the photosynthetic membrane⁵¹.

⁴⁶ S. Anjum, X. Xie, L. Wang, M. Saleem, C. Man, & W. Lei, *Morphological, physiological ...*, cit.

⁴⁷ S. Basu, V. Ramegowda, A. Kumar, & A. Pereira, *Plant adaptation to drought stress*, in «F1000Research 5 (F1000 Faculty Rev)», 2016.

⁴⁸ S. Anjum, X. Xie, L. Wang, M. Saleem, C. Man, & W. Lei, *Morphological, physiological ...*, cit.

⁴⁹ *Ibid.*

⁵⁰ S. Basu, V. Ramegowda, A. Kumar, & A. Pereira, *Plant adaptation...*, cit.

⁵¹ *Ibid.*

4. *Pesticides as technologies of domestication*

Tsing's contributions bring us directly into blasted landscapes, anthropogenic environments⁵², and what has been called a «postnatural world»⁵³. This section reflects on crops as a potentially paradigmatic form of life for the Anthropocene, or rather for a Plantationocene⁵⁴. It does so by highlighting how crops exemplify domesticated species, as they dwell in the supremely anthropogenic environment built by agricultural practices. Pesticides are our entry point into this scenario: synthetic pesticides are emblematic of globalised forms of industrial agricultural production and labour⁵⁵, which at once dictate a hierarchical relationship between humans and other forms of life, and unevenly spread toxicity and associated health risk⁵⁶.

Indeed, multispecies attention has emerged in parallel with theories on the Anthropocene: the acknowledgement of humans' geological, epochal impact on Earth, as well as an attempt to look for non-anthropocentric ways of being in the world⁵⁷. Among the many conceptualisations of the current epoch (Anthropocene, Wastocene, Chthulucene), we briefly touch on the word that resonates the most with the object at hand: Plantationocene⁵⁸. Interdisciplinary studies of «a Plantationocene»⁵⁹ choose to

⁵² A.L. Tsing, *On Anthropogenic ...*, cit.

⁵³ T. van Dooren, E. Kirksey & U. Münster, *Multispecies studies...*, cit., p. 3.

⁵⁴ D. Haraway, *Anthropocene, capitalocene, plantationocene, chthulucene: Making kin*, in «Environmental Humanities», VI, 1, 2015, pp. 159-65.

⁵⁵ B. Mansfield, M. Werner, C. Berndt *et al.*, *A new critical social science research agenda on pesticides*, in «Agriculture and Human Values», XLI, 2, 2024, pp. 395-412.

⁵⁶ T. Davies, *Slow violence and toxic geographies: 'Out of sight' to whom?*, in «Environment and Planning C: Politics and Space», XL, 2, 2019, pp. 409-427.

⁵⁷ N. Clark, & K. Yusoff, *Geosocial Formations and the Anthropocene*, in «Theory, Culture & Society», XXIV, 2-3, 2017, pp. 3-23.

⁵⁸ D. Haraway, *Anthropocene, capitalocene...*, cit.

⁵⁹ M. Barua, R.I. Martín & M. Achtnich, *Introduction: Plantationocene*, in «Theorizing the Contemporary, Fieldsights»; 2023, M. Barua, R.I., Martín, & M. Achtnich, *Introduction: Plantationocene* (available at <https://www.culanth.org/fieldsights/series/plantationocene>).

highlight «the devastating transformation of diverse kinds of human-tended farms, pastures, and forests into extractive and enclosed plantations, relying on slave labor and other forms of exploited, alienated, and usually spatially transported labor»⁶⁰. This scholarly and political effort has further highlighted plants' agencies, with a specific attention on how they exist in anthropogenic environments. Maan Barua, specifically, has focused on three such kinds: the «vegetal agency of plants put into circulation by plantations, vegetal economies centered on labor power and the work plants do, as well as the vegetal politics of landscape change»⁶¹; our contribution focuses on the first type of agency. Our paper takes on these reflections, and aims to provide further examples of how crop plants deal with existence in violently-created «simplified ecologies»⁶². Agricultural crops are our focus as examples of domesticated plants *par excellence*. To better explain this, we briefly explore contemporary notions of domestication as a lens for understanding the agency of crops in anthropogenic environments. In biology, «domestication refers to the status of a plant, domesticated rather than wild, marked by adaptations to human-maintained ecology, with life cycles linked to cultural scheduling of ecosystem management»⁶³. Longstanding narratives have indeed described the Neolithic Revolution as the moment when humans affirmed their mastery over nature through agriculture and the selection and breeding of crops⁶⁴. These ideas

⁶⁰ D. Haraway, *Anthropocene, capitalocene...*, cit., p. 162; for a reflection on the interrelationship between capitalism, the slave trade, and the current climate crisis, see Katherine McKittrick's work on plantations (K. McKittrick, *Plantation futures*, in «Small Axe: A Caribbean Journal of Criticism», XVII, 3, 2013, pp.1-15, doi: 10.1215/07990537-2378892).

⁶¹ M. Barua, R.I., Martín, & M. Achtnich, *Introduction: Plantationocene...*cit., p. 13.

⁶² *Ibid.*

⁶³ D.Q. Fuller, T. Denham & R. Allaby, *Plant domestication and agricultural ecologies*, in «Current Biology», XXXIII, 11, 2023, p. 637.

⁶⁴ V. G. Childe, *The Most Ancient East: The Oriental Prelude to European Pre-history*, Kegan Paul, Trench, Trubner, London 1928.

have later been profoundly criticised, both for their accuracy⁶⁵ and for their political implications. Marianne Elisabeth Lien, Heather Anne Swanson, and Gro B. Ween, in their *Introduction to Domestication Gone Wild*, describe how the mainstream story of domestication was built in parallel with - and as a justification of - the affirmation of specific relations of domination⁶⁶. These narratives helped frame Euro-American societal hierarchies and ideals as universal and “naturally” superior. They also helped to «prop up troubling human social formations - -including racial hierarchies and the domination of women, patriarchal family structures, reproductive control, naturalized notions of European kinship, and concepts of the household and the domestic - that underpin nation-states as well as imperial colonising projects»⁶⁷. Rather than human mastery over nature, Tim Ingold has reflected on domestication as “human involvement in establishing the conditions for growth” of other species⁶⁸. Embracing this input, we follow an idea of domestication that is not based on a hierarchy between species, and neither one that equates being domesticated with a lack of agency. Ingold’s perspective of growth opens up possibilities for framing domestication as a mutual, reciprocal process of coevolution. Indeed, historical biologists have studied the changes that humans have undergone because of their tightening relationships with specific plant species. For instance, cattle-based societies have developed lactase persistence in adults⁶⁹, while cereal growing groups have developed an increased amylase

⁶⁵ B.D. Smith, *Low-- Level Food Production*, in «Journal of Archeological Research», IX, 1, 2001, pp. 1-43.

⁶⁶ M.E. Lien, H. A. Swanson, & B. W. Gro, *Introduction...*, cit.

⁶⁷ *Ibid.*, p. 9.

⁶⁸ T. Ingold, *Growing plants ...*, cit., p. 21.

⁶⁹ P. Gerbault, A. Liebert, Y. Itan, A. Powell, M. Currat, J. Burger, D. Swallow & M. Thomas, *Evolution of lactase persistence: an example of human niche construction*, in «Philosophical Transactions of the Royal Society B: Biological Science», CCCLXVI, 2011, pp. 863-877.

gene copy number⁷⁰. In this sense, «human fitness has [...] increased as a result of its relationship with domesticated species», but these non-human actors have themselves constructed the conditions for their propagation and continued relationship with humans⁷¹. Theories that take genes as the fundamental unit of evolution – following Dawkins' *The Selfish Gene* – have gone as far as maintaining that humans have been themselves domesticated for the propagation of specific genetic sequences⁷².

With these notions in mind, we take on pesticides as a channel for revealing the agency of crops in heavily anthropogenic conditions. Agricultural pesticides are, following Tim Ingold's perspective, emblematic of human attempts to determine the conditions of growth for crops. Thus, they provide avenues for seriously engaging with the agency of plants in situations in which their environment is decisively determined by anthropogenic forces. Studying the agency of crops in their interactions with synthetic pesticides is a way to reflect on the effects of the domesticating intention of humans; however, it is also an insight into how crops are domesticating agents in their own right. We demonstrate these ideas in the next two sections; the first one reflects on crops' agency under pesticide-related conditions, while the latter highlights how crops themselves perceive their environment and actively synthesise pest-controlling substances.

⁷⁰ G. H. Perry, N. Dominy, K. Claw, H. Fiegler, R. Redon, J. Werner, F. Villanea, J. Mountain, R. Misra, N. Carter, C. Lee & A. Stone, *Diet and the evolution of human amylase gene copy number variation*, in «Nature Genetics», XXXIX, 10, 2007, pp. 1256–1260; F. Luca, G. Perry, & A. Di Rienzo, *Evolutionary adaptations to dietary changes*, in «Annual Review of Nutrition», XXX, 2010, pp. 291–314.

⁷¹ M. D. Purugganan, *What is domestication?*, in «Trends in Ecology & Evolution», XXXVII, 8, 2022, pp. 663–671, p. 666.

⁷² R. Dawkins, *The Selfish Gene* (1976), Oxford University Press, Oxford 2016; R.G. Bednarik, R.G. *The Domestication of Humans*, in «Anthropologie», XLVI, 1, 2008, pp. 1–18.

5. *Plants and Pesticide Stress*

Plant growth regulators by Jan, Singh, Bhardwaj, Ahmad, and Kapoor⁷³ provides a comprehensive overview of the concept of pesticides. Pesticides are any compounds existing naturally or intended to terminate, restrain or mutate the life cycle of any pest. They vary based on their chemical structure, role, mobility, target rates or toxicity. While insecticides, rodenticides, herbicides, and fungicides are formulated to target insects, rodents, weeds, and fungi respectively, their effects on crop plants can vary significantly. Generally, plants' capacity to uptake pesticides changes between species or subspecies, as well as pesticide concentration and their hydrophobicity are relevant⁷⁴. Plants' responses are multiple based on their capacities to accumulate, transform, volatilize or stimulate other mechanisms⁷⁵. We explain these three plant responses through *Phytoremediation of organochlorine pesticides*⁷⁶.

Firstly, Singh T. and Singh D.K. describe the ability of some plants to accumulate pesticides based on root absorption through passive or active mechanisms. Some pesticides are not blocked by the plant's root system but they enter through cell walls and intercellular space, cell to cell through plasmodesmata, and transmembrane by crossing cell membranes repeatedly. Also, accumulation can even occur when contaminant particles in air are deposited on plant leaves by interception, sedimentation and diffusion and then cuticle permeation is not an issue.

⁷³ S. Jan, R. Singh, R. Bhardwaj, P. Ahmad, & D. Kapoor, *Plant growth regulators: a sustainable approach to combat pesticide toxicity*, in «3 Biotech», X, 466, 2020.

⁷⁴ P. Schröder, *Exploiting plant metabolism for the phytoremediation of organic xenobiotics*. In N. Willey (ed.), *Phytoremediation: Methods and reviews 23*, Humana Press, Totowa 2007, pp. 251-263; H. Kaur, R. Kaur, S. Singh, N. Jagota & A. Sharma, *Pesticide biology in plants: Plant uptake, translocation, and accumulation*. In A. Sharma, V. Kumar & B. Zheng (ed.) *Pesticides in the Environment*, Elsevier, Amsterdam 2024, pp. 67-86.

⁷⁵ T. Singh, & D.K. Singh, *Phytoremediation...*, cit.

⁷⁶ *Ibid.*

The transformation process triggers a three-phase detoxification system that involves the storage of pesticides in various parts of the plant⁷⁷. In the first step, the xenobiotic (i.e. the pesticide) is modified in a derived form through the addition of various chemical groups involving hydrolysis, oxidation or reduction⁷⁸. The addition caused a major activation of molecules directing phase two as well as increasing polarity or rather more water solubility⁷⁹. In the second step, pesticides are conjugated with amino acids, glucose or glutathione in the cytosol⁸⁰. The accumulation of conjugated compounds in the cytosol can be harmful, as they may interact with enzymes, potentially disrupting other cellular processes and possibly reverting to toxic metabolites⁸¹. In the third step, a secondary conjugation is possible but the main object is the compartmentalization of less toxic pesticides, critical to finalize the detoxification process⁸². They are stored in vacuoles, apoplasts or attach to cell wall/lignins based on their solubility⁸³.

Finally, Singh T. and Singh D.K.⁸⁴ also provide an illustration of plant stimulation. It is based on enhancing microorganisms' detoxification processes in the rhizosphere, or rather, around plant roots. Plants increase the bioavailability of xenobiotics, boosting the activity of degradative enzymes in bacteria such as

⁷⁷ *Ibid.*; Jan, R. Singh, R. Bhardwaj, P. Ahmad, & D. Kapoor, *Plant growth regulators...*, cit.; H. Kaur, R. Kaur, S. Singh, N. Jagota, & A. Sharma, *Pesticide biology in plants...*, cit.

⁷⁸ Jan, R. Singh, R. Bhardwaj, P. Ahmad & D. Kapoor, *Plant growth regulators...*, cit.

⁷⁹ J. Coleman, M. Blake-Kalff & E. Davies, *Detoxification of xenobiotics by plants: chemical modification and vacuolar compartmentation*, in «Trends in Plant Science», II, 1997, pp. 144–151.

⁸⁰ Jan, R. Singh, R. Bhardwaj, P. Ahmad, & D. Kapoor, *Plant growth regulators...*, cit.

⁸¹ J. Coleman, M. Blake-Kalff, & E. Davies, *Detoxification of xenobiotics by plants...*, cit.

⁸² Jan, R. Singh, R. Bhardwaj, P. Ahmad, & D. Kapoor, *Plant growth regulators...*, cit.

⁸³ P. Schröder, *Exploiting plant metabolism...*, cit.; Jan, R. Singh, R. Bhardwaj, P. Ahmad, & D. Kapoor, *Plant growth regulators...*, cit.; H. Kaur, R. Kaur, S. Singh, N. Jagota, & A. Sharma, *Pesticide biology in plants...*, cit.

⁸⁴ T. Singh, & D. K. Singh, *Phytoremediation...*, cit.

Klebsiella sp., *Pseudoarthrobacter sp.*, or *Pseudomonas sp.* Plants contribute by adsorbing pollutants through mucigel, cell walls, and membrane lipids; altering pH, especially for ionizable substances; and producing phytosurfactants that increase the solubility of hydrophobic compounds. The synergy between plants and microbes forms a sophisticated ecological network, so essential that the absence of either partner would undermine the entire system.

6. Ecosystem and Pesticide Stress - Phytoremediation Technology

The use of synthetic pesticides has only increased over the past decades, as the absence of pesticides causes loss of fruits, vegetables, and cereals respectively of 78, 54 and 32%, and, for example, a decrease in US exports of cotton, wheat and soybean by 27%⁸⁵. The pesticides' fate, after their application in the fields, is determined by processes such as volatilization, surface runoff into water bodies, leaching into groundwater, and sorption by soil⁸⁶. Consequently, pesticides have «persisting and long term effects on the ecological contributors»⁸⁷. Pesticides' side-effects often are increasing populations of some species while decreasing others with the end result being an altered community structure, which can lead to either a decline or an improvement in the ecosystem's functionality⁸⁸. The pesticides' effect on living cells may cause changes in the cellular enzyme activities or cell structure modification⁸⁹.

⁸⁵ M. El Oirdi, M. Yaseen, U. Farwa, M.A. Raza, M. Farhan, Z.A. Sandhu, F. Ali, M.S. Aatif, H.S. Khan & I. Nahvi, *Crops and people: The dangers and potential benefits of pesticides*, in «Soil & Crop Sciences», X, 1, 2024.

⁸⁶ *Ibid.*

⁸⁷ V. Kumar, P. Kumar & J. Singh, *An introduction to contaminants in agriculture and Environment* in V. Kumar, P. Kumar, J. Singh, & R. Kumar (Ed.), *Contaminants in Agriculture and Environment: Health Risks and Remediation*, Agriculture and Environmental Science Academy, Haridwar 2019, p. 4.

⁸⁸ F. Sánchez-Bayo, *Indirect effect of pesticides on insects and other arthropods*, in «Toxics», IX, 8, 2021, p. 177.

⁸⁹ E. Brunk, R.L. Chang, J. Xia, H. Hefzi, J.T. Yurkovich, D. Kim & B.O. Palsson, *Characterizing posttranslational modifications in prokaryotic*

What makes the situation even more concerning is the transport of xenobiotic substances along the food chain. Their strong affinity for non-polar environments leads to significant accumulation in adipose tissue⁹⁰. Kumar describes the process of biomagnification: plant enzyme-proteins bind to these pollutants and transport them within the plant⁹¹. Herbivores then consume the contaminated plants or plant products, promoting the transfer of pollutants up the food chain, ultimately reaching humans. Finally, higher trophic levels have more levels of pesticides than primary⁹². Also, varying concentrations of pesticides were found across different human age groups, indicating accumulation over a lifetime⁹³.

Pesticides often have negative effects on various components of the ecosystem, even as crop plants themselves act as agents within it. Our aim is to understand how plants once again take a leading role in ecological recovery, using the very same mechanisms that make them agents in the first place. Indeed, phytoremediation takes a close, narrow look at agricultural practices that notice and pay attention to more-than-human agency and arrangements. Specifically, humans domesticate crops by fencing off land and managing plantations through the controlled introduction of resources. We acknowledge and support the directionality of this process, but we especially emphasize its bidirectionality. When plants act as agents, they may develop conflictual responses to pesticides, while other ecosystem components often suffer negative consequences without necessarily playing an agentive role. Indeed,

metabolism using a multiscale workflow, in «Proceedings of the National Academy of Sciences», CXV, 43, 2018, pp. 11096-11101.

⁹⁰ É. Dewailly, G. Mulvad, H.S. Pedersen, P. Ayotte, A. Demers, J.P. Weber & J.C. Hansen, *Concentration of organochlorines in human brain, liver, and adipose tissue autopsy samples from Greenland*, in «Environmental Health Perspectives», CVII, 10, 1999, pp. 823-828.

⁹¹ V. Kumar, P. Kumar & J. Singh, *An introduction to contaminants...*, pp 1-8, cit.

⁹² T. Singh, & D. K. Singh, *Phytoremediation...*, cit.

⁹³ É. Dewailly, G. Mulvad, H. S. Pedersen, P. Ayotte, A., Demers, J.P. Weber & J.C. Hansen, *Concentration of organochlorines in human brain...*, cit.

the fields of ecotoxicology and toxicology reveal the unintended harmful effects of pesticide use. Our goal is to demonstrate the bidirectional nature of domestication within an anthropized and polluted ecosystem, using as an example the pathway to recovery that can emerge through mechanisms such as phytoremediation.

Phytoremediation technologies, the collaboration between plants and microorganisms, reveal promising new capacities for the absorption and detoxification of polluted soil or water⁹⁴. Growing literature is bringing our attention to the role of microorganisms and microbial actions on the mutually reinforcing cycles that connect soils, plants, and human gut microbiomes⁹⁵. This synergy relies on plants' unique ability to carry out complex detoxification processes, and to, again, leverage multi-species relationships in order to do so.

Phytoremediation and detoxification of xenobiotics in plants by Del Buono, Terzano, Panfili, and Bartucca has been instrumental in deepening our understanding of the various phytoremediation strategies⁹⁶. They define several types of phytoremediation, including those targeting pesticides. Phytoextraction involves the plant's ability to absorb contaminants through its root system, translocating them to harvestable parts – thus preventing their use for food. Phytovolatilization refers to the plant's capacity to absorb and release contaminants into the atmosphere. Phytofiltration promotes the absorption and accumulation of

⁹⁴ T. Singh & D.K. Singh, *Phytoremediation...*, cit.

⁹⁵ G. Berg, *Plant-microbe interactions promoting plant growth and health: perspectives for controlled use of microorganisms in agriculture*, in «Applied Microbiology and Biotechnology», LXXXIV, 1, 2009, pp. 11-18; H. Hirt, *Healthy soils for healthy plants for healthy humans. How beneficial microbes in the soil, food and gut are interconnected and how agriculture can contribute to human health*, in «EMBO reports», XXI, 8, 2020; T. Linder, *Beyond Agriculture—How Microorganisms Can Revolutionize Global Food Production*, in «ACS Food Science & Technology», III, 7, 2023, pp. 1144-1152.

⁹⁶ D. Del Buono, R. Terzano, I. Panfili & M.L. Bartucca, *Phytoremediation and detoxification of xenobiotics in plants: herbicide-safeners as a tool to improve plant efficiency in the remediation of polluted environments. A mini-review*, in «International Journal of Phytoremediation», XXII, 8, 2020, pp. 789-803.

pollutants in aquatic environments. Phytodegradation relies on species capable of enzymatically transforming pollutants, representing a key plant defense mechanism against pesticides. Lastly, phytostimulation involves the release of organic compounds by plants that stimulate microbial activity in the soil. In this context, identifying the plant species most capable of breaking down pesticides efficiently and in large quantities becomes crucial, depending on location, depth and aging of pollution. For instance, plants with dense root systems are able to better investigate the ground, while deep rooting species can act upon high depths of pesticides accumulation⁹⁷.

In the complex mechanisms described above, plants emerge as recurring protagonists. Pesticides are applied to guarantee the growth of plants, prompting them to activate their own detoxification pathways to mitigate harmful effects. However, non-target organisms often suffer significant side effects, issues that humans frequently attempt to solve once again through plant-based strategies. Humans, in their excessive use of some pesticides, end up contaminating entire ecosystems, including themselves. Yet it is through plants, via mechanisms like phytoaccumulation and phytostimulation, that viable ways can be found to remediate the damage. In essence, the very pollution caused in the name of protecting plants can be addressed through the natural capacities of plants themselves.

7. Conclusion

Synthetic pesticides – expression of the «global pesticide complex»⁹⁸ – are at the centre of global agricultural networks which are based on a hierarchical separation of human and the rest of nature, and informed by the very politics «that have been

⁹⁷ P. Schröder, *Exploiting plant metabolism...*, cit.

⁹⁸ R.E. Galt, *Beyond the circle of poison: significant shifts in the global pesticide complex 1976–2008*, in «Global Environmental Change», XVIII, 4, 2008, pp. 786–799.

central to projects of patriarchal domination and state control»⁹⁹. They represent the current anthropogenic epoch – be it Anthropocene, Plantationocene, or else – very well, exemplifying human efforts to organise nature, and the inescapable presence of toxicity in any environment. They are also an environmental stressor against which crop plants have developed adaptations and filtration mechanisms. In this sense, they represent an anthropogenic determinant for the agency of nonhuman life. We observed them as an entry point for reflecting on agriculture as a domestication practice. However, we reframed domestication in order to highlight the negotiable dimension inherent in organising another species’ environment of growth, and the spaces for agency that are always present, even amidst toxicity and at the margins of global production systems¹⁰⁰.

Our paper acknowledges the issue of the global pesticide complex in its devastating effects for environmental health. It responds to the many transdisciplinary calls for turning towards nonhumans in order to imagine different ways of being on our planet. Taking the agency of crop plants seriously means being offered conceptual pathways for this endeavour. First of all, we have seen how crop plants act to change themselves and enact change around them regardless of how toxic we may deem the context in which they act. In understanding that plants have agency in anthropogenic context, we also see that they can live in blasted, contaminated worlds – as is the case, for instance, for Tsing’s *Matstutake*¹⁰¹. In this sense, the agency of plants asks us to reflect on what it means to live with and amidst toxicity. It shows us that seeking “natural” practices replicates a separation between humans and the rest of biological life, while they are so clearly intertwined. We are rather asked to ground ourselves into the human and nonhuman world

⁹⁹ M.E. Lien, H.A. Swanson & B.W. Gro, *Introduction...*, cit., p. 23.

¹⁰⁰ A.L. Tsing, *Provocation...*, cit.

¹⁰¹ A.L. Tsing, *The Mushroom at the End of the World...*, cit.

we inhabit, and to look for avenues for coexistence in the agencies and actions of various companions¹⁰².

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¹⁰² D. Haraway, *Anthropocene, capitalocene...*, cit.; A.L. Tsing, *Provocation...*, cit.