2

Cast into the Stones of International Law

A Critique of the UPOV Standards in the Light of Scientific Insights and Policy Shifts toward Agroecology and Natural Farming

Mrinalini Kochupillai and Julia Köninger

ABSTRACT

This contribution critically considers how assumptions underlying international treaties on intellectual property (IP) reflect, and impact upon, realities. International IP treaties and international agreements that set minimum standards and so harmonize and co-ordinate norm-setting among and within states, frequently codify underlying assumptions about the social, economic, cultural or environmental utility of the standards they aim to globalize. While these assumptions may be correct in particular territorial, historical and socio-economic contexts, once they are engrained in standards that are cast into the stones of international treaty law, they become global norms that are at best difficult, and at times factually impossible to implement, amend or adapt. In worst case scenarios, the habitual implementation of such laws can lead to significant socio-economic, cultural and environmental deterioration. Whenever an implementation of such standards does not materialize the underlying assumptions, the global norms ultimately become redundant, which more broadly challenges their legitimacy. Using the international protection of plant varieties as an example, this

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contribution critically reviews the assumptions built into the UPOV treaty regime and whether they are supported by science and empirical research on biodiversity, food security, nutrition and seed sovereignty. Contrary to expectations, this redundancy may extend beyond the context of biodiversity-rich countries of the Global South into countries of the Global North that are also struggling with (agro)biodiversity losses and climate change.

TABLES OF CONTENTS

A. INTRODUCTION

An ancient Indian proverb says that "[i]t is because lions are lazy, snakes are scared, and intellectuals have difference of opinions, that there is happiness on the planet."

This proverb highlights the importance of diversity[1] in opinions, approaches, interpretations, and perspectives – whether it be in economic, social, political, regulatory, or scientific discourse. Diversity is not only critical for the growth and development of any democracy but also for the evolution of social, economic, legal, and scientific thought. Needless to say, diversity is also critically important for innovation.

The central relevance of diversity for innovation is particularly obvious in the agricultural seeds sector.[2] Yet, international intellectual property (IP) regulations in this sector have long assumed that "uniformity" and "homogeneity"[3] rather than "diversity" and "heterogeneity," are of central relevance for the protection and incentivization of innovation. With this assumption, several other assumptions have followed, particularly the assumption that only plant breeders in the formal sector[4] – but not farmers in the informal sector – can innovate and create new plant varieties that are capable, inter alia, of ensuring food security.[5]

Yet, this assumption and the focus on "uniform" and "stable" seeds has led to an alarming loss in crop biodiversity (and associated diversity in human nutrition) over the past century. According to estimates from the United Nations Food and Agriculture Organization (UN FAO), more than 75 percent of crop genetic diversity has been lost since the widespread adoption of conventional agriculture based on a very few crop varieties.[6] Today, 75 percent of the world's food derives from only twelve plants; world nutrition is primarily based on ten crops, of which three – rice, corn and wheat – contribute nearly 60 percent of the calories and proteins obtained by humans from plants.[7]

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[1] Sanskrit proverb quoted and explained by R. Shankar, "Learning From Mistakes," 2014, www.artofliving.org/wisdom/learning-from-mistakes (last accessed May 27, 2021).

[2] Mrinalini Kochupillai, *Promoting Sustainable Innovations in Plant Varieties*, vol. 5 (Springer, 2016), pp. 11–14; K. Rerkasem and Michael Pinedo-Vasquez, "Diversity and innovation in smallholder systems in response to environmental and economic changes," *Managing Biodiversity in Agricultural Ecosystems*. Columbia University Press, NY (2007), p. 362; Eric J. B. von Wettberg et al., "Ecology and genomics of an important crop wild relative as a prelude to agricultural innovation," *Nature Communications* 9, no. 1 (2018), p. 9.

[3] From a commercial perspective, replicability and scalability determine the success of a variety. "Scalability" implies without the loss of uniform and distinctive features by which one can tell a seed and its produce apart from those of others.

[4] Seed sector innovators have been classified into two groups: (i) formal innovators, i.e., plant breeders affiliated with universities, research institutions or the seed industry, and (ii) informal innovators, i.e., farmers (particularly small and marginal farmers, who constitute almost 80 percent of the farming community in the Global South). See Shawn McGuire and Louise Sperling, "Seed systems smallholder farmers use," *Food Security* 8, no. 1 (2016), p. 180.

[5] Food and Agriculture Organization of the United Nations, The seed sector and food security (2001), www.fao.org/3/Y2722E/y2722e0d.htm (last accessed June 06, 2021).

[6] FAO, "What is happening to agrobiodiversity?" (1999), www.fao.org/3/y5609e/y5609e02.htm (last accessed June 06, 2021).

[7] *Supra* note 6.

Further, international IP regulations, particularly the UPOV Plant Breeders' Rights (PBR) regime, also assume that managing the genetic makeup of seeds (i.e., ensuring genetic purity, uniformity, and stability) and protecting the resulting varieties with PBRs, patents, or a combination of the two, is adequate to optimally protect, and thereby incentivize, seed innovations; notably, seed innovations by the formal sector. What is emphasized by the UPOV and PBR regime, therefore, is the "internal environment" of a seed. In practical reality, however, to manifest the goodness (or the best) of the uniform and stable internal seed environment, the external environment has to be carefully managed and maintained by those who buy and use the seeds. If this is not done, the internal genetic environment of the seed fails to deliver on its promised goodness (e.g. in the form of high yields). In other words, uniform and stable seeds only perform *ceteris paribus*.

The UPOV–PBR regime therefore also presumes that it is possible, in all or most circumstances, to meticulously manage the external environment a seed is faced with (e.g. in terms of optimal irrigation, fertilizer and pesticide usage, and soil quality). This assumption is a rather hefty one, largely divorced from the realities of marginal environments and subsistence farms, which include over 40 percent of the Earth's drylands, particularly in Africa (13×10^6 km^2) and Asia (11×10^6 km^2).[8] Even within the European Union, 29 percent of the agricultural area is farmed in marginal environments.[9]

Further, the existing system that mandates a focus on uniformity and stability to incentivize and protect innovations excludes farmers in the informal sector from the seed innovation landscape in two ways. First, the system fails to recognize the fact of farmers' innovations (i.e., farmer-selection-based in-situ improvements in seeds from generation to generation).[10] Second, by regulatory or policy-driven insistence on the cultivation of "uniform" seeds, which by definition have narrow genetic makeups, the possibility of (downstream) innovations by farmers is severely restricted.[11] Yet, perhaps ironically, the possibility of both (upstream) informal and (downstream) formal innovations increases if the starting point is genetically variable, indigenous and heterogenous seeds.

Assumptions that underlie international treaties are expected to reflect, as well as impact upon, realities. This is equally true for international IP treaties and various

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[8] Robin P. White, Daniel B. Tunstall, and Norbert Henninger, *An Ecosystem Approach to Drylands: Building Support for New Development Policies* (World Resources Institute, 2002), p. 2.

[9] B. Elbersen et al., "Mapping marginal land potentially available for industrial crops in Europe" (paper presented at the 26th European Biomass Conference & Exhibition, 2018), p. 72.

[10] See for example, the story of HMT Rice, as well as Farmers' Varieties application trends in India, in Kochupillai, *supra* note 3, pp. 113–22. See also Mrinalini Kochupillai, "Is UPOV 1991 a good fit for developing countries?" in *Innovation Society and Intellectual Property*, ed. J. Drexl and A. Sanders (Edward Elgar, 2019a), p. 44.

[11] Kochupillai, *supra* note 10; Zewdie Bishaw and Michael Turner, "Linking participatory plant breeding to the seed supply system," *Euphytica* 163, no. 1 (2008).

international agreements that set minimum standards aimed at harmonizing and coordinating norm-setting among and within states. These assumptions, as well as the (minimum) legal standards they result in, are of a scientific, socio-economic, political or mixed nature, depending on the subject matter of the treaty or agreement. Therefore, international treaties and agreements frequently codify the underlying assumptions about the social, economic, cultural and/or environmental utility of the standards they aim to globalize.

These assumptions may be correct in particular territorial, historical, scientific or socio-economic contexts. However, once they are engrained in international standards that are cast into the stones of international treaty law, they become global norms that are at best difficult, and at times even factually impossible to implement, amend or adapt to suit local realities. In worst case scenarios, the habitual implementation of such laws can lead to significant socio-economic, cultural, as well as environmental deterioration. Empirical research has revealed, for example, that innovations in the agricultural seed sector, supported by IP laws and associated seed replacement policies, have gradually eroded the culture of farmer-to-farmer seed sharing and seed exchange.[12] This culture was crucial for in-situ seed conservation and farmer improvement of seeds from location to location and generation to generation. Habitual implementation of such laws can also distort and artificially limit scientific research endeavors and reduce, rather than optimize, equitable and inclusive innovations by all potential innovators.[13] At the same time, whenever the implementation of such standards does not lead to the materialization or manifestation of the underlying assumptions, the global norms may ultimately become redundant, more broadly challenging their legitimacy.

Using the international protection of plant varieties as an example, this contribution critically reviews the assumptions built into the UPOV treaty regime. It examines whether those assumptions are supported by current science and empirical research on the importance of (agro)biodiversity for sustainable agriculture, food security, and nutrition. The article also highlights recent regulations and policies that embrace emerging scientific findings and empirical trends and indicate a possible future trend toward the redundancy of norms. Contrary to expectations, this redundancy may extend beyond the context of biodiversity-rich countries of the Global South into countries of the Global North that are also (and perhaps more severely) struggling with (agro)biodiversity losses and climate change.[14]

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[12] Kochupillai, *supra* note 2, pp. 222, 226.

[13] Kochupillai, *supra* notes 2 and 10.

[14] WWF, LIVING PLANET REPORT 2020 – Bending the curve of biodiversity loss, WWF (2020), www.zsl.org/sites/default/files/LPR%202020%20Full%20report.pdf (last accessed June 06, 2021).

I. *Research Questions*

This contribution was guided by the following research questions:

1. What scientific presumptions underlie the UPOV treaty and the PBR regime it establishes?
2. What scientific presumptions underlie the Convention on Biological Diversity (CBD) and the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA)?
3. What is the scientific and historical basis of the regulatory focus on uniformity or homogeneity and stability? Does this focus correspond with current and emerging scientific understanding of how sustainability can be ensured in agricultural production and innovation?
4. In what way, if at all, does agricultural biodiversity support food security and seed-related innovations?

These questions are explored in this paper with a relatively long-term perspective. The aim is to determine whether a fundamental rethinking of international IP regulations is called for to promote and incentivize what has been previously referred to as "sustainable innovations" in plant varieties.[15]

II. *Arrangement of the Paper*

The paper is arranged as follows. Following this introduction, Section B briefly explores the assumptions that underlie the UPOV agreement and the PBR regime it establishes. Specifically, Section B discusses the meaning and scope of the key terms under PBR regimes, giving special attention to the historical scope of the term "variety" and the scientific and commercial basis of the focus on "uniformity" (or homogeneity) and "stability." Section C explores the assumptions underlying the CBD and the International Treaty on Plant Genetic Resources for Food and Agriculture (the ITPGRFA, also known as the Seed Treaty). Section C specifically discusses the scientific basis of the importance given to "diversity" (contained in landraces and farmers' varieties) and "traditional knowledge" in the CBD and the Seed Treaty. Section C also looks into current scientific research that highlights the importance of and the inter-relationship between seed and soil (microbial) diversity for the performance of indigenous or heterogenous seeds in marginal environments. A related point is the limited utility of "uniform" seeds in such environments and in the face of climate change.

In Section D, the value of traditional (ecological) knowledge vis-à-vis protection and enhancement of agrobiodiversity (i.e., seed and soil microbial diversity) is explored in the context of the natural farming (NF) movement in India. Section

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[15] Kochupillai, *supra* note 2, p. 15.

E concludes with exploring recent legislation in Europe that indicates a sort of "return to innocence," focusing, once again, on the importance of local seed and food diversity in the face of climate change and the ongoing global pandemic. Section E also makes recommendations for further research and highlights the need to urgently redirect international effort toward more diversity, supporting "minimum standards" in IP and associated regulations.

B. ASSUMPTIONS UNDERLYING UPOV

I. *(Botanical) Varieties versus (Legal) Varieties*

The International Union for the Protection of New Varieties of Plants (UPOV) was established by the International Convention for the Protection of New Varieties of Plants (UPOV Convention). The Convention itself was adopted in Paris in 1961 and was revised in 1972, 1978 and 1991. According to the UPOV website, "UPOV's mission is to provide and promote an effective system of plant variety protection, with the aim of encouraging the development of new varieties of plants, for the benefit of society."[16]

The UPOV focuses on promoting and protecting new "plant varieties." The term "plant variety" is considered to have neither a scientific nor a botanical origin.[17] Its origin as well as rise to popular usage are usually traced to the UPOV Convention of 1962. However, the term "variety" has a legal as well as a botanical origin. In the legal context, the term "variety" was indeed defined, perhaps for the first time, by UPOV,[18] under Article 2.2 of its 1962 Act, which states:[19] "For the purposes of this Convention, the word 'variety' applies to any cultivar, clone, line, stock or hybrid which is capable of cultivation and which satisfies the provisions of subparagraphs (1) (c) and (d) of Article 6." Article 6(1)(c) and (d) go on to describe the "homogeneity" and "stability" requirement that every "cultivar, clone, line, stock or hybrid" must fulfill to be deemed a "new variety" and to qualify for protection:

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[16] www.upov.int/portal/index.html.en.

[17] European Patent Office, "Definition of the term 'plant varieties,'" ed. Case Law of the Boards of Appeal. www.epo.org/law-practice/legal-texts/html/caselaw/2019/e/clr_i_b_3_1_1.htm (last accessed November 21, 2021).

[18] See Sabine Demangue, *Intellectual Property Protection for Crop Genetic Resources: A Suitable System for India* (Herbert Utz Verlag, 2005), p. 18.

[19] It is relevant to note that there existed a legal definition of "plant variety" from the year 1962 at least. Several cases in the European Union also have accepted that the concept of "Plant Varieties" has been borrowed from the UPOV convention. See Demangue, *supra* note 18, p. 132, citing T 320/87 (Hybrid Plants/Lubrizol) point 12 of the reasons; T 49/83 (Propagating material/CIBA-GEIGY) point 2 of the reasons; T56/93 (Plant Cells/PLANT GENETIC SYSTEMS), point 23 of the reasons; G 1/198 (Transgenic Plants/NOVARTIS II), point 3.1 of the reasons.

(c) The new variety must be sufficiently homogeneous, having regard to the particular features of its sexual reproduction or vegetative propagation.
(d) The new variety must be stable in its essential characteristics, that is to say, it must remain true to its description after repeated reproduction or propagation or, where the breeder has defined a particular cycle of reproduction or multiplication, at the end of each cycle.

In the European Union, the Biotechnology Directive[20] clarifies the meaning of (plant) varieties by stating that "a variety is defined by its whole genome and therefore possesses individuality and is clearly distinguishable from other varieties."[21] Recital 31 adds that "a plant grouping which is characterized by a particular gene (and not its whole genome) is not a plant variety."[22] The 1991 Act of UPOV substantially modified the definition of "variety" and replaced the "homogeneity" requirement with the "uniformity" requirement. UPOV 1991 states:

> (vi) "variety" means a plant grouping within a single botanical taxon of the lowest known rank, which grouping, irrespective of whether the conditions for the grant of a breeder's right are fully met, can be
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> – defined by the expression of the characteristics resulting from a given genotype or combination of genotypes,
> – distinguished from any other plant grouping by the expression of at least one of the said characteristics and
> – considered as a unit with regard to its suitability for being propagated unchanged;

Thus, under the legal definition, in order to be deemed a "variety," (i) the plant grouping must exhibit specific characteristics that result from a given genotype, that is, from the "internal environment" of the seed as a whole, or in other words, from its entire genome and not due to the expression of a particular gene; (ii) these characteristics (or at least one of them) should help distinguish it from any other plant grouping; and (iii) the plant grouping must be capable of propagating itself unchanged.

It is in the context of botanical taxons and ranks mentioned in the above legal definition of "variety," that one can also find the botanical meaning of the term. The International Code of Nomenclature for Algae, Fungi and Plants[23] places the term

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[20] Directive 98/44/EC of the European Parliament and of the Council of 6 July 1998 on the legal protection of biotechnological inventions (Biotechnology Directive).

[21] See Directive 98/44/EC of the European Parliament and of the Council of 6 July 1998 on the legal protection of biotechnological inventions, Recital 30, Official Journal L 213, 30/07/1998, pp. 13–21 (1998). See Demangue, p. 133 *supra* note 18.

[22] See Demangue, *supra* note 18, p. 133.

[23] Chapter 1, Article 4.1 of the International Code of Nomenclature for algae, fungi and plants states: 4.1. The secondary ranks of taxa in descending sequence are tribe (tribus) between family and genus, section (sectio) and series (series) between genus and species, and variety (varietas) and form (forma) below species. See ISHS Secretaria, "The International Code of Nomenclature for Cultivated Plants (ICNCP)" (2009), http://www.ishs.org/scripta-horticul

"variety (*varietas*)" as the category in the botanical nomenclatural hierarchy that comes between species and form (forma).[24]

This botanical usage of the term "variety" pre-dates the adoption of UPOV and has been defined differently by various notable botanists. The emergence of the term was highly influenced by Darwin's work on the evolution of species.[25] One of the earliest definitions of "variety" was by Linnaeus, who in 1753, in the *Species Plantarum*, defined "variety" as "a plant changed by accidental cause due to the climate, soil, heat, wind, etc. It is consequently reduced to its original form by a change of soil. Further, the kinds of varieties are size, abundance, crispation, colour, taste, smell. Species and genera are regarded as always the work of nature, but varieties are more usually owing to culture."[26]

The reference to "culture" in the botanical definition of "variety" is significant as it indicates the very localized nature of a "variety" and that various cultural contexts can lead to the evolution, in various geographies, of diverse varieties belonging to the same species (or sub-species). The interpretation of Linnaeus' work by Fernald (1940) confirms this understanding. Fernald opined that Linnaeus "generally designated as varieties indigenous plants which he considered to be natural (often geographic) variations within the broad limits of his specific concept." [27] In later works, botanists have distinguished between "sub-species" and "varieties," with the former term used to indicate "major morphological variations" or "variations of greater value," while the latter indicates "minor ones [variations]."[28]

Asa Gray, a leading botanist in nineteenth-century America, however, said in 1836 that "any considerable change in the ordinary state or appearance of a species is termed a variety. These arise for the most part from two causes, viz.: the influence of

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turae/international-code-nomenclature-cultivated-plants-ninth-edition (last accessed June 06, 2021).

[24] Life forms are grouped or classified using a taxonomic hierarchy. The taxonomic rank "life" is followed by "domain," "kingdom," "phylum," "class," "order," "family," "genus," and "species." In the plant kingdom, the rank of species is followed by "subspecies," "variety," and then "form."

[25] Karen Hunger Parshall, "Varieties as incipient species: Darwin's numerical analysis," *Journal of the History of Biology* 15, no. 2 (1982), p. 199.

[26] As translated by Ramsbottom in 1938, see J. Ramsbottom, "Linnaeus and the species concept," Proceedings of the Linnaen Society of London (1938), pp. 192–219, p. 199. See also Robert T. Clausen, "On the use of the terms 'subspecies' and 'variety'," *Rhodora* 43, no. 509 (1941): p. 159.

[27] Merritt Lyndon Fernald, "Some spermatophytes of eastern North America," *Contributions from the Gray Herbarium of Harvard University*, no. 131 (1940) cited in Clausen, *supra* note 26, p. 160.

[28] Others, however, disagreed with Fernald and found Linnean varieties had little to do with geographic limitations but were "minor variations in colour, leaf-cutting, crispation, pubescence, habit and similar characters," although an "occasional one is geographically significant." See Clausen, *supra* note 26, p. 160. Also, the American Code of Botanical Nomenclature (1907) used the term "subspecies" for variations, and relegated the term "variety" to horticultural usage (see Clausen at page 163, quoting from the American Code of Botanical Nomenclature).

external circumstances,[29] and the crossing of races."[30] Here we see, therefore, that before the era of genetic engineering rose to prominence, varieties were known to result not just from "crossing" (i.e. breeding activities that seek to change the "internal environment" of the seed) but also by natural environmental factors (i.e. the "external environment" to which a seed is subjected). In other words, it is not just the "internal atmosphere" of a seed, but also its external environment that determines its characteristics.

Indeed, today geneticists confirm that the seed's external environment – which contributes specific nourishment, inter alia, through soil and manure quality as well as biotic and abiotic stressors – determines which genes will express themselves and which will remain dormant.[31] This principle is particularly relevant when the seed's internal genetic environment has not been artificially narrowed with the aim of ensuring "uniformity" and "stability" in specific external conditions.

Undoubtedly, the term "variety" is now less frequently used in the field of botany,[32] with preference given to the more important differences reflected under the taxonomic ranks of "species" and "sub-species". However, it is important to note that the botanical term "variety," which reflects "minor" differences, does not presuppose "uniformity" or "stability" either within the same farmland (due to shifting environmental circumstances) or across various geographic, environmental, soil type and other factors. In fact, within specific species and sub-species, a variety (in the botanical sense) can be expected to naturally display different characteristics depending on various external factors and influences. Further, the changes seen in any such botanical "variety" can originate from the work not just of plant breeders but also of farmers, inter alia, based on cultural preferences and environmental expediencies.

It is, therefore, quite interesting that some countries, while following a definition of variety that is very close to the above UPOV definition,[33] also recognize a different category – called "farmers' varieties." In India, for example, "farmers' varieties" are defined to include landraces and wild relatives of a variety. To this extent, the Indian law seems to include both the legal and botanical understanding of "variety" within its scope. Section 2(l) of the Indian law states:

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[29] See also discussion under Section B. II. of this chapter.

[30] Asa Gray, *Elements of Botany* (G. & C. Carvill & Company, 1836) as cited in Kuang-Chi Hung, "Finding Patterns in Nature: Asa Gray's Plant Geography and Collecting Networks (1830s–1860s)" (2013), doctoral dissertation, p. 77.

[31] Ya-Nan Chang et al., "Epigenetic regulation in plant abiotic stress responses," *Journal of Integrative Plant Biology* 62, no. 5 (2020), pp. 575–576.

[32] By the early 1900s, the term "variety" started being disfavored by botanists due to its broad and non-specific nature, often indicative only of "minor" differences. Indeed, various experts opined that the most important unit under the rank "species" should be the "ecotype," carefully determined by experiment and by plotting distributions on maps and analyzing specimen plants both cytologically and genetically. It is noteworthy here that botanists can often detect "geographic and ecological variations" of ecotypes that are classified as taxonomic subspecies. Clausen, *supra* note 26, pp. 163–164.

[33] But which excludes "combination of genotypes" under the first bullet point.

> 2(l) “farmers’ variety” means a variety which
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> (i) has been traditionally cultivated and evolved by the farmers in their fields; or
> (ii) is a wild relative or land race of a variety about which the farmers possess the common knowledge;

Wild relatives and landraces[34] differ significantly from UPOV’s “varieties” because they can and do change during the course of repeated cycles of propagation. This change occurs as a result of the genetic variability inherent in heterogenous (as opposed to homogenous) propagation materials (such as seeds), and is triggered, inter alia, by external circumstances such as climate change, pest attacks, drought or flood conditions. While genetic variability makes landraces and farmers’ varieties more robust in the face of biotic and abiotic stresses, it is antithetical to “uniformity” and “stability” requirements, which are pre-conditions for the grant of PBR certificates under UPOV.

II. *The Scientific (Ir)rationale of the DUS Requirement*

The test of distinctness, uniformity, and stability (DUS) is referred to as the “DUS requirement.” The legal concept of uniformity can be traced back to the “homogeneity” requirement under the 1962 UPOV Act, which became “uniformity” in the later Acts. Hence, UPOV 1991 (Article 8) defines a “uniform” variety rather generally: ‘A variety shall be deemed to be uniform if, subject to the variation that may be expected from the particular features of its propagation, it is sufficiently uniform in its relevant characteristics.’

The regulatory focus on uniformity can be traced back to the (re)discovery of Mendelian genetics in the early 1900s[35] Gregor Johann Mendel published his understanding of the laws of heredity in 1865. However, the dissemination of the findings in the scientific and political community followed only in 1900, rediscovered by K. E. Correns, E. von Tschermak and H. de Vries.[36] They rejected “breeding methods inspired by Darwin’s evolutionary theory” as “scientifically

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[34] A landrace is defined as a “dynamic population of a cultivated plant that has a historical origin, a distinct identity and lacks formal crop improvement, as well as often being genetically diverse, locally adapted and associated with traditional farming systems” in Tania Carolina Camacho Villa et al., “Defining and identifying crop landraces,” *Plant Genetic Resources* 3, no. 3 (2005), pp. 373, 381.

[35] Christophe Bonneuil, “Seeing nature as a ‘universal store of genes’: how biological diversity became ‘genetic resources’, 1890–1940,” *Studies in History and Philosophy of Science Part C: Studies in History and Philosophy of Biological and Biomedical Sciences* 75 (2019), p. 3.

[36] Michael Blakeney, *Intellectual Property Rights and Food Security* (Cabi, 2009), p. 79.

unsound" and not feasible for practical breeding[37] and focused instead on Mendel's theory of heredity based on the stability of genes.[38]

Johannsen emphasized the purity of genetic material;[39] he considered "the genotype as a whole as the elementary species and the pure line, as the key permanent biological type."[40] In the early 1900s, with the expanding practice of plant breeding, the understanding that genetic purity is rare and actually leads to instability was increasingly overtaken by the understanding that genetic purity and stability are indicative of quality and replicability.[41] Early geneticists considered genetic identity to be independent of environmental influence; that is, gene expression is not influenced by the plant's environment but is primarily or exclusively influenced by the internal genetic makeup of the plant (i.e. the plant genome).[42] This idea led to a sort of obsession with genetic purity and stability that continues in the plant breeding community to date.[43] According to Provine (1971), "the climate of biological opinion was favorable to the pure line theory."[44] Opposing ideas tying genetics closely to its context (e.g. environment) were led by Raphael Weldon but ended prematurely with his death in 1906.[45] When Johannsen presented his pure

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[37] Bowler called this "The eclipse of Darwinism," see Peter J. Bowler, *The Eclipse of Darwinism: Anti-Darwinian Evolution Theories in the Decades around 1900* (JHU Press, 1992), p. 15. While nineteenth-century biology's emphasis was on continuous change, exchange, and admixture as fundamental properties of life and as driving forces of evolution, early twentieth-century biologists, by contrast put the emphasis on isolation as the driving force of speciation (the synthetic theory of evolution), see Bonneuil, "Producing identity, industrializing purity: Elements for a cultural history of genetics," A *Cultural History of Heredity* 4 (2008), p. 91.

[38] "Mendel's theory of heredity relies on equality and stability throughout all stages of the life cycle" according to Petr Smýkal et al., "From Mendel's discovery on pea to today's plant genetics and breeding," *Theoretical and Applied Genetics* 129, no. 12 (2016), p. 2267.

[39] W. Johannsen, "Heredity in populations and pure lines," Classic Papers in Genetics (1903).

[40] Blakeney, *supra* note 36; Bonneuil, *supra* note 37, citing Frederick B. Churchill, "William Johannsen and the genotype concept," *Journal of the History of Biology* 7, no. 1 (1974).

[41] Bonneuil, *supra* note 37, p. 98.

[42] Mary Douglas, *An Analysis of the Concepts of Pollution and Taboo* (London: Ark, 1966). Bonneuil, *supra* note 37, p. 105, stated that "in the wide cultural shift from the 19th to the 20th century, a deep and intrinsic genetic identity was constructed for living organisms, separated from the influence of the place and the environment."

[43] In 1890, Proskowetz proposed a race catalogue of materials (varieties) at the International Congress for Agriculture and Forestry in Vienna, E. von Proskowetz and F. Schindler, "*Welches Werthverhältnis besteht zwischen den Landrassen landwirthschaftlicher Culturpflanzen und den sogenannten Züchtungsrassen*" (paper presented at the *Internationaler land- und forstwirthschaftlicher Congress zu Wien*, 1890), p. 3; Bonneuil, *supra* note 35; Bonneuil, *supra* note 37.

[44] William B. Provine, "The origins of theoretical population," *Genetics*. Chicago: University of Chicago Press (1971), p. 108.

[45] Gregory Radick, "Challenges to Data Linkage in Plants: Two Parables from the Pea" in: ed. Sabina Leonelli and Hugh Williamson, Towards Responsible Plant Data Linkage: Global Challenges for Food Security and Governance, Springer Nature (forthcoming). Also, Gregory Radick, Disputed Inheritance: The Battle over Mendel and the Future of Biology, Chicago: University of Chicago Press (forthcoming), p. 559, https://press.uchicago.edu/ucp/books/book/chicago/D/bo183632870.html.

line theory at a symposium in 1910, most geneticists accepted the theories without adequate proof[46] and Mendelism's legacy "boomed its way into biology."[47]

There are, indeed, also more economically driven reasons for the continuing importance given to pure and stable genetic materials: pure and stable genetic material leads to uniform and stable plant varieties that can be easily protected by PBR and patents. The existence of property rights permits the charging of monopoly rents and recoupment of the (allegedly) high costs involved in the creation, certification and marketing of new uniform varieties.[48] Further, industrial standardization and quality control regulations have allowed and supported the emergence of the breeding industry[49] and effectively limited competition from the informal seed sector (in Europe). Industrial breeders, therefore, can be said to have considerably contributed to the success of Mendel's and Johannsen's theories.[50]

Pure (parental) lines, purified for specific traits, are also a prerequisite for the creation of F1 hybrids.[51] These F1 hybrids, in turn, help industrial breeders maintain their market monopolies in two ways: (i) once two (or more) parental lines are crossed to create an F1 hybrid, it is difficult to identify (or recreate) the parents. This is because the resulting hybrid out-performs both parents due to a phenomenon known as hybrid vigor or heterosis;[52] (ii) F1 hybrids do not reproduce true to type. This means that farmers who attempt to save seeds from the harvest of their F1 seeds for sowing the next season's crop are likely to experience lowering of yields due to the segregation of genetic materials in the second generation.[53]

Experts argue that it was perhaps no coincidence that the dissemination of Mendelian theory in the early 1900s coincided with the industry push for property rights for new inventions and discoveries in agriculture.[54] To ensure "quality

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[46] "In 1910 [sic] the pure line theory seemed so obvious that most outstanding geneticists accepted it without adequate proof. Most of them also accepted the related selection theory, and the two ideas became firmly associated." Provine, *supra* note 44.

[47] Radick, *supra* note 45, p. 5.

[48] Harvey E. Lapan and GianCarlo Moschini, "Innovation and trade with endogenous market failure: The case of genetically modified products," *American Journal of Agricultural Economics* 86, no. 3 (2004), p. 647.

[49] Bonneuil, *supra* note 37, p. 98. See also Blakeney, *supra* note 36.

[50] Berris Charnley and Gregory Radick, "Intellectual property, plant breeding and the making of Mendelian genetics," *Studies in History and Philosophy of Science Part A* 44, no. 2 (2013), p. 223.

[51] F1 hybrids are the first filial generation resulting from cross-mating of distinctly different parent types, having vigor, which is a manifestation of heterozygosity and which allows breeders to improve the performance of resulting generations. W.E. Timberlake, "Heterosis," in Stanley Maloy and Kelly Hughes, Brenner's Encyclopedia of Genetics, Elsevier Science (2013), p. 2; N. U. Khan, "F1 Hybrid," https://www.sciencedirect.com/science/article/pii/B978012809633806413X

[52] Timberlake, *supra* note 51.

[53] A. Riaz et al., "Genetic diversity of oilseed Brassica napus inbred lines based on sequence-related amplified polymorphism and its relation to hybrid performance," *Plant Breeding* 120, no. 5 (2001).

[54] Blakeney, *supra* note 36, p. 79.

control," the purity and stability criteria of plant material became the norm not only for industrial seed production but also in experimental biology, and as a means of ensuring "fairness in social and economic relations."[55]

The standardization of plant breeding and its focus on uniformity and purity caused a divide between landraces, which are preserved and improved over time by farmers in situ, versus cultivars, which result from plant breeders' labs or from highly regulated and carefully managed agricultural testing lands.[56] Landraces were considered "not suitable for anything," obsolete, unproductive and were reduced to a mere gene store[57] – as indicated in the popular term "plant genetic resources". A resolution in 1907 on conserving landraces[58] by a locally oriented public initiator "soon came under private breeders' fire" leading to its decline.[59] However, as a paradox of modern breeding, the breeder Baur (1914) warned of their disappearance and the urgent need to preserve landraces.[60]

What has resulted since the widespread acceptance of Mendelian genetics and the "pure line" theory is a systematic exclusion of farmers (as seed sellers) from the agricultural seed market, especially in Europe.[61] This resulted in a whole array of undesirable consequences, including the erosion of agricultural biodiversity and the rapid conversion to conventional farming, heavily reliant on expensive chemical inputs.[62]

Arguably, therefore, the requirements of "uniformity" and "stability" have been introduced into the legal definition of "plant variety" through a legal fiction because genetic purity, uniformity and stability are important primarily from a legal (and industrial) standpoint, and not from scientific or (marginal) farm-environment perspectives. An expert has stated that "the scientific notion does not necessarily coincide with the legal concept. The law may require certain characteristics for a protected variety that may not be essential for a scientific definition."[63]

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[55] Bonneuil, *supra* note 37, pp. 99, 100.

[56] Bonneuil, *supra* note 37, p. 95.

[57] Bonneuil, *supra* note 35, p. 3, citing Erwin Baur, *Die Bedeutung der primitiven Kulturrassen und der wilden Verwandten unserer Kulturpflanzen für die Pflanzenzüchtung* (*éditeur non identifié*, 1914). See also Radick, *supra* note 45.

[58] VIII. *Internationaler Landwirtschaftlicher Kongress Wien*. Mai, 21–25 1907. Organisation. Vienna: Versay, vol. 1, p. 282.

[59] Bonneuil, *supra* note 35, p. 3.

[60] Baur, *Die Bedeutung der primitiven Kulturrassen und der wilden Verwandten unserer Kulturpflanzen für die Pflanzenzüchtung Jahrbuch Deutsche Landwirt. Gesell.* (*Saatzuchtabteilung*), 1914.

[61] Elise Demeulenaere and Yvonne Piersante, "In or out? Organisational dynamics within European 'peasant seed' movements facing opening-up institutions and policies," *The Journal of Peasant Studies* 47, no. 4 (2020), pp. 1–3.

[62] Jonathan Harwood, *Europe's Green Revolution and Others Since the Rise and Fall of Peasant-Friendly Plant Breeding* (Routledge, 2012), p. 144.

[63] Blakeney, *supra* note 36, p. 88.

In fact, as stated previously, pure, uniform and stable lines are able to perform well only in carefully managed environments because, contrary to the claims of early geneticists, a plant's genetic identity is not independent of its environment but is highly influenced by it.[64] More recently, historians of science have attempted to emphasize again the importance of taking environmental influences into account, together with the inherent genetic makeup of seeds, to avoid the "determinism" that results from a focus exclusively on a seed's "internal" environment.[65] In this context, the following explanation is helpful:[66]

> This observation can be better understood by the following scientific facts: the physical properties (including shape, size, yield, pest resistance etc.) of a plant are dependent on its environment as well as on its genotype (i.e. genes and genetic structure).[67] Environmental variations as well as genetic variations will therefore affect the phenotype of a crop.[68] Environmental variations cannot be built into the genetic makeup of a crop. However, formal crop improvement (plant breeding) programs can manage the genetic makeup of a crop.… In order to ensure that a formally bred seed or plant is selected on the basis of its "nature" (i.e. genetic makeup) and not its "nurture" (i.e. the environment in which it is grown), formal plant breeders breed plants in as uniform an environment as possible.[69] It is expected (or presumed) that these uniform environments will also be reproducible in commercial or actual farmers' fields. It is for this reason that formally bred cultivars often fail in natural environments that are not engineered to mimic the breeders' ideal environments. Landraces and traditional varieties that have high genetic variability, on the other hand, are able to perform even in the most adverse of natural farm conditions because of their inherent genetic variability.…[70] In

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[64] Mashamba Philipo, Patrick A Ndakidemi, and Ernest R Mbega, "Environmental and genotypes influence on seed iron and zinc levels of landraces and improved varieties of common bean (Phaseolus vulgaris L.) in Tanzania," *Ecological Genetics and Genomics* 15 (2020); Monica Rodriguez et al., "Genotype by environment interactions in barley (Hordeum vulgare L.): different responses of landraces, recombinant inbred lines and varieties to Mediterranean environment," *Euphytica* 163, no. 2 (2008). Others have found temperature and access to light to significantly impact seed development, see Hanzi He et al., "Interaction between parental environment and genotype affects plant and seed performance in Arabidopsis," *Journal of Experimental Botany* 65, no. 22 (2014). These facts continue to be a cause of great concern for plant breeders. The increasing importance given to devices related to the Internet of Things and remote-sensing data to ensure "climate smart" and "precision" agriculture is aimed at minimizing problems resulting from these unpredictable changes in the environment and climate.

[65] Gregory Radick, "Teach students the biology of their time," *Nature News* 533, no. 7603 (2016).

[66] Kochupillai, pp. 53–54 *supra* note 2.

[67] Kochupillai, *supra* note 2 (note 18 in original source).

[68] Kochupillai, *supra* note 2 (note 19 in original).

[69] Kochupillai, *supra* note 2 (note 20 in original, citing George Acquaah, *Principles of Plant Genetics and Breeding* (John Wiley & Sons, 2009), p. 79.

[70] Kochupillai, *supra* note 2 (note 21 in original, citing Villa et al., *supra* note 35, p. 374, who state that landrace conservation is closely associated with food security and that landraces play an increasingly important role in alternative farming systems, such as organic farming).

> developing countries where a large percentage of farmers do not have the means to simulate artificial perfect farm conditions, the importance of landraces becomes even more apparent. [Footnotes are renumbered here.]

This is where we can start to understand the relevance of agrobiodiversity contained in farmers' varieties and landraces. We discuss this in further detail in the following section.

C. ASSUMPTION UNDERLYING THE CONVENTION ON BIOLOGICAL DIVERSITY (CBD) AND THE SEED TREATY

I. *The Scope and Importance of 'Diversity' and 'Traditional Knowledge'*

We saw above that UPOV assumes and emphasizes the central importance of "uniformity", "stability" and related "genetic homogeniety" or "purity". The CBD and the Seed Treaty, on the other hand, assume and emphasize the importance of (agro)biodiversity. Since its inception, the CBD has underscored the importance of biodiversity within the soil (i.e. the soil microbiome) and on the soil (i.e. seed or plant biodiversity). Equally relevant is the recognition and high status given within the CBD to the valuable role played by traditional knowledge and associated systems, practices, and innovations in maintaining this biodiversity and using it in a sustainable manner (CBD, Articles 8(j), 17). The CBD also mandates the sharing of social and economic benefits ("benefit sharing") with the people preserving and using this knowledge in situ.[71]

Equitable benefit sharing is presumed necessary not only to ensure fair compensation for sharing biodiversity and associated know-how, but also to ensure that communities engaged in its protection and in-situ conservation have monetary incentives to continue their important work.[72] Similar to the CBD's focus on biodiversity generally, the Seed Treaty focuses on agrobiodiversity, especially agricultural seed diversity and mechanisms to conserve, preserve and protect this diversity, while facilitating its equitable use through benefit sharing.

"Conservation" and "preservation," however, are unfortunate terms in the context of agrobiodiversity.[73] This is not least because farmers and farmer communities not only conserve this diversity but constantly improve it and innovate with it, with the help of traditional and indigenous know-how and technologies. Indeed, the CBD encourages international "cooperation for the development and use of technologies, including indigenous and traditional technologies, in pursuance of the objectives of

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[71] CBD, "Convention on Biological Diversity," Article 2 (1992): Article 10.

[72] Mrinalini Kochupillai et al., "Incentivizing research & innovation with agrobiodiversity conserved in situ: Possibilities and limitations of a blockchain-based solution," *Journal of Cleaner Production* (2021).

[73] Kochupillai, pp. 30–31, *supra* note 10.

the Convention."[74] The relevance of traditional technologies and associated traditional ecological knowledge (TEK), is, however, context-dependent. To understand the context, it is useful to revisit the development of "high yielding varieties" (HYVs) during the "Green Revolution." Prior to the development of HYVs by Norman Borlaug, "lodging" was witnessed when traditional (indigenous) wheat seeds were treated with mineral fertilizers: they would grow rapidly and prematurely fill up with grain, the weight of which made them "lodge" and die before they were ready for harvest.[75]

The breeding of semi-dwarf "high yielding" wheat and rice seed varieties (HYVs) under the Green Revolution resolved a twofold problem: the problem of traditional varieties being non-responsive to fertilizer-treated soils[76] and the problem of lodging.[77] The new development paved the way for bumper crops and the promise of economic and social prosperity for all farmers. Indeed, the notion that scientific intervention for the creation of "new varieties" is necessary for high yield and food security was also propelled in the Global South, at least in part, by the demonstrated success of Norman Borlaug's HYVs.[78]

What is not discussed in the success story of the Green Revolution is its impact on indigenous seeds and landraces that were *not* engineered to withstand the application of mineral fertilizers. The claim that the cultivation of indigenous seeds that incorporate agrobiodiversity and genetic variability is not adequate for food security needs to be considered in this context. Studies that compare the productivity of landraces with that of improved varieties on fertilizer-treated soils can, therefore, be expected to show lower yields for landraces and farmers' varieties than for seeds whose genetic environment is engineered to perform in such soils.[79] Therefore, the rapid expansion of conventional agriculture involving the regular use of mineral fertilizers and chemical pesticides with "improved" seeds (and the corresponding disappearance of TEK-based farming systems) is also one of the main threats to landraces and in-situ agrobiodiversity conservation.[80]

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[74] CBD, "CONVENTION ON BIOLOGICAL DIVERSITY," Article 18.4.

[75] Adnan Noor Shah et al., "Lodging stress in cereal – effects and management: an overview," *Environmental Science and Pollution Research* 24, no. 6 (2017).

[76] Thomas F. Döring et al., "Comparative analysis of performance and stability among composite cross populations, variety mixtures and pure lines of winter wheat in organic and conventional cropping systems," *Field Crops Research* 183 (2015), p. 240; Odette D. Weedon and Maria R. Finckh, "Heterogeneous winter wheat populations differ in yield stability depending on their genetic background and management system," *Sustainability* 11, no. 21 (2019), p. 9.

[77] Ayako Okuno et al., "New approach to increasing rice lodging resistance and biomass yield through the use of high gibberellin producing varieties," *PLoS ONE* 9, no. 2 (2014).

[78] In India, economic and political pressures also led to the systematic replacement of traditional diversity-based crops and farming systems with uniform, homogenous-varieties based monocultures. Kochupillai, *supra* note 2, pp. 86–91.

[79] Rodriguez et al., *supra* note 64, p. 244.

[80] Nadia Benbrahim et al., "On-farm conservation of Zaer lentil landrace in context of climate change and improved varieties competition," *Journal of Agricultural Research* 5 (2017), p. 79.

Yet, landraces and indigenous or farmers' varieties, when cultivated in TEK-based farming systems, have been found to outcompete hybrid varieties in highly variable environments,[81] offering a robust local strategy for food security, including coping with climate change.[82] They may also economically benefit (marginal) smallholder farmers by granting them independence from cost-intensive inputs such as breeders' seeds, mineral fertilizers and pesticides while helping to revive and conserve local traditional knowledge.

In the following sub-sections, we look closer into the current scientific understanding of the importance of diversity and variability contained in landraces and the impact of plant genetic diversity on soil health and the nutrition contained in food.

II. *The Relevance of Landraces and Genetic Variability*

We saw in the previous section that modern genetics and the science of plant breeding developed under the aegis of Mendel's theory of heredity, supported by pure line theories proposed by scientists such as Johanssen.[83] However, as early as 1972, the US report "Genetic Vulnerability of Major Crops" attracted attention in science:[84] it found genetic uniformity to be the source of vulnerability to plant diseases and abiotic or biotic stresses. The report challenged dominant scientific thought and the national policies that relied on it.

However, although scientists take the blame for the focus on uniformity, notably, the markets (and consumers) also demand uniformity (e.g. in the form size, shape, color, texture of vegetables and grains).[85]

Not surprisingly, therefore, today the legal fictions and assumptions underlying UPOV continue to unchangeably favor Mendel's theory of heredity and the pure line theory. Empirical and scientific evidence opposing these theories is, however, accumulating. Various studies find higher variety and variability of plant genetic resources to be more efficient than pure lines. For example, increased within-crop genetic diversity has been found to enhance yield stability and yield reliability while permitting rapid and dynamic response to change (e.g. changes in climatic or biotic stresses).[86]

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[81] Rodriguez et al., *supra* note 64.

[82] Benbrahim et al., *supra* note 80; Ana Carolina Feitosa Vasconcelos et al., "Landraces as an adaptation strategy to climate change for smallholders in Santa Catarina, Southern Brazil," *Land Use Policy* 34 (2013).

[83] Raoul A. Robinson, "Breeding for quantitative variables. Part 2: Breeding for durable resistance to crop pests and diseases," in *Plant Breeding and Farmer Participation*, FAO, Roma, Italy (2009), p. 368.

[84] National Research Council, Genetic Vulnerability of Major Crops., National Academy Of Sciences (Washington, DC, 1972).

[85] V. Ramanatha Rao, A. H. D. Brown and M. Jackson, *Managing Plant Genetic Diversity* (Cabi, 2001), p. 6.

[86] Döring et al., *supra* note 76.

Unlike pure lines and hybrids created in artificial or carefully managed environments, landraces are, by definition, unique to the region where they evolve.[87] Undoubtedly, farming – including farming with landraces or farmers' varieties – reduces the overall plant or natural biodiversity. However, cultivation with indigenous landraces, rather than with uniform and stable seeds, helps to increase, or at least maintain, *agro*biodiversity. In this context, it is useful to revisit the distinction between genetic variation and genetic variability, as discussed in significant detail elsewhere:[88]

> Genetic variation is synonymous with genetic diversity or biodiversity. . ..[89] Genetic variability, on the other hand, refers to the ability of the genetic make-up of a specific crop variety [sic] (or landrace) to transform or adapt itself to varying biotic and abiotic stresses.[90] The process of creating a landrace in a region leads to the reduction of the genetic pool or genetic variation seen within that region prior to the commencement of agriculture there in. However, individual landraces, although displaying a certain genetic integrity, have a high level of genetic variability that equips them to withstand specific biotic and abiotic stresses within the local area where they were developed.[91] This genetic variability therefore confers on landraces, their peculiar suitability to local climatic and soil conditions and their superior ability to resist pests and diseases, particularly those endemic to a specific geographic and climatic region. [Footnotes are renumbered here but are shown as they appear in the original.]

In other words, the genes of landraces are highly variable due to continuous evolution in the face of unpredictable phenological events. This variability helps landraces adapt to varying biotic and abiotic stresses, such as weather extremes or pest attacks, making them more climate-resilient than improved and uniform varieties.[92] For example, lucerne landraces from five countries learned to cope differently with environmental stress situations, such as drought (Italian landraces)

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[87] Villa et al., *supra* note 34, p. 37.

[88] Kochupillai, *supra* note 2, p. 52.

[89] Noel Kingsbury, *Hybrid: The History and Science of Plant Breeding* (Chicago and London: University of Chicago Press, 2009), pp. 39–42. The CBD uses the term "variability" in its definition of Biological Diversity (Article 2), defining "diversity" as "the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part: this includes diversity within species, between species and of ecosystems."

[90] Acquaah, *supra* note 70, p. 79.

[91] Kingsbury, *supra* note 90.

[92] Pauline Chivenge et al., "The potential role of neglected and underutilised crop species as future crops under water scarce conditions in Sub-Saharan Africa," *International Journal of Environmental Research and Public Health* 12, no. 6 (2015); Sangam L. Dwivedi et al., "Landrace germplasm for improving yield and abiotic stress adaptation," *Trends in Plant Science* 21, no. 1 (2016).

or salt-stress environments (Moroccan landraces).[93] Lima bean landraces showed high adaptability to drought, temperature stress and competitiveness under such conditions, compared to commercial cultivars.[94] In unfavorable areas of Morocco[95] and China,[96] landraces are preferably cultivated due to their better adaptability and better yields. Farmers planting a higher diversity of corn in Mexico are better able to mitigate the weather extremes caused by climate change.[97] In Turkey, farmers prefer a local wheat landrace that can be sown twice per year, minimizing the risk of harvest losses.[98] As observed by Kochupillai,[99]

> it is due to this genetic variability that landraces (in association with traditional farming practices) are often found by empirical and scientific research to outperform modern "improved" varieties in various environments, notably marginal environments.[100] Landraces are therefore also crucial for long-term food security, especially in developing countries where a large percentage of farmers cultivate crops in marginal environments where improved varieties do not perform. [Footnote is renumbered here.]

However, it is also this genetic variability inherent in landraces and farmers' varieties that make them heterogenous (rather than homogenous or "uniform"). Landraces and farmers' varieties are, therefore, unsuitable for protection by PBR, even when a landrace is significantly distinctive from other landraces or farmers' varieties.

III. *Seed–Soil Interactions, Nutrition and Environmental Sustainability*

Plant genetic materials co-evolve with their surrounding microorganisms, forming a holobiont.[101] Plant root secretions and associated soil microorganisms together constitute the root microbiome. The soil surrounding the plant root, which is

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[93] P. Annicchiarico et al., "Adaptation of landrace and variety germplasm and selection strategies for lucerne in the Mediterranean basin," *Field Crops Research* 120, no. 2 (2011).

[94] María Isabel Martínez-Nieto et al., "Resilience capacity assessment of the traditional Lima Bean (*Phaseolus lunatus* L.) landraces facing climate change," *Agronomy* 10, no. 6 (2020).

[95] Benbrahim et al., *supra* note 80.

[96] Li, J., van Bueren, E. T. L., Jiggins, J. and Leeuwis, C. "Farmers' adoption of maize (*Zea mays* L.) hybrids and the persistence of landraces in Southwest China: implications for policy and breeding," *Genetic Resources and Crop Evolution* 59, no. 6 (2012), pp. 1147–1160.

[97] Carolina Ureta et al., "Maize yield in Mexico under climate change," *Agricultural Systems* 177 (2020).

[98] D. Bardsley and I. Thomas, Valuing local wheat landraces for agrobiodiversity conservation in Northeast Turkey. *Agriculture, Ecosystems & Environment* 106, no. 4 (2005), pp. 407–412.

[99] Kochupillai, *supra* note 2, p. 53.

[100] Villa et al., *supra* note 34, p. 374, stating that landrace conservation is therefore closely associated with food security.

[101] "Holobiont" describes a biological entity composed of the sum of the composed host and associated microorganisms. Eugene Rosenberg and Ilana Zilber-Rosenberg, "The hologenome concept of evolution after 10 years," *Microbiome* 6, no. 1 (2018).

particularly rich in beneficial microbiological activity, is called the rhizosphere.[102] The more diverse the microbial population in the rhizosphere, the better the symbiotic exchange between plants and microorganisms, supporting nutrient exchange[103] and resulting in higher nutrient content in the plant, vegetable, or crop.[104] Intimate associations between the plant root and soil microbes are also critical for the establishment and maintenance of stable relations between plant hosts and rhizobial microorganisms (host-microbial homeostasis),[105] which is crucial for plant disease suppression.[106]

Interestingly, it is not just the quality of the soil that impacts seeds and crops, but the plant genotype, in turn, influences the root microbiome[107] and, consequently, plant–microbe interactions. Evolutionary changes in host genotypes influence the bacterial selection process, determining the richness, diversity, and relative abundances of taxa.[108] For example, for barley, the community composition at the root–soil interface significantly declined from wild genetic resources to landraces to uniform plant varieties.[109]

Plants also co-evolve with microorganisms that are hosted in their cell walls (endophytes).[110] These microorganisms offer various advantages to host plants, such as the production of phytohormones[111] or the solubilization of nutrients such as phosphorus.[112] These microorganisms are also crucial for the germination of seeds[113]

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[102] Roeland L. Berendsen, Corné M. J. Pieterse, and Peter A. H. M. Bakker, "The rhizosphere microbiome and plant health," *Trends in Plant Science* 17, no. 8 (2012).

[103] Marcel G. A. Van Der Heijden et al., "A widespread plant-fungal-bacterial symbiosis promotes plant biodiversity, plant nutrition and seedling recruitment," *The ISME Journal* 10, no. 2 (2016).

[104] Wendy Sangabriel-Conde et al., "Native maize landraces from Los Tuxtlas, Mexico show varying mycorrhizal dependency for P uptake," *Biology and Fertility of Soils* 50, no. 2 (2014).

[105] M. Amine Hassani, Paloma Durán and Stéphane Hacquard, "Microbial interactions within the plant holobiont," *Microbiome* 6, no. 1 (2018).

[106] Alberto Pascale et al., "Modulation of the root microbiome by plant molecules: the basis for targeted disease suppression and plant growth promotion," *Frontiers in Plant Science* 10 (2020).

[107] Marie-Lara Bouffaud et al., "Root microbiome relates to plant host evolution in maize and other P oaceae," *Environmental Microbiology* 16, no. 9 (2014); Derek S. Lundberg et al., "Defining the core Arabidopsis thaliana root microbiome," *Nature* 488, no. 7409 (2012).

[108] Bouffaud et al., *supra* note 107.

[109] Davide Bulgarelli et al., "Structure and functions of the bacterial microbiota of plants," *Annual Review of Plant Biology* 64 (2013).

[110] Eric B. Nelson, "Microbial dynamics and interactions in the spermosphere," *Annual Review of Phytopathology* 42 (2004).

[111] Phytohormones are plant hormones regulating plant metabolism and consequently plant growth; additionally, they play a vital role in plants' defence response mechanisms against stresses, see Dilfuza Egamberdieva et al., "Phytohormones and beneficial microbes: essential components for plants to balance stress and fitness," *Frontiers in Microbiology* 8 (2017).

[112] Kusam Lata Rana et al., "Endophytic microbes from diverse wheat genotypes and their potential biotechnological applications in plant growth promotion and nutrient uptake," Proceedings of the National Academy of Sciences, India Section B: Biological Sciences (2020).

[113] Joanne C. Chee-Sanford et al., "Do microorganisms influence seed-bank dynamics?," *Weed Science* 54, no. 3 (2006).

and for fighting seed-borne diseases.[114] While a part of these microorganisms (bacteria) are vertically transmitted from parent to progeny seedlings,[115] at around 45 percent,[116] other parts are horizontally transmitted and are impacted by environmental characteristics such as the soil microbiome,[117] climatic conditions, and human practices.[118]

Further, research comparing older landraces of wheat,[119] breadfruit,[120] soybeans,[121] and corn[122] with more modern varieties found the older ancestors benefited more from symbiotic associations with mycorrhizal fungi (mycorrhiza root colonization).[123] The mycorrhiza root colonization of landraces exceeded that of modern hybrid cultivars by 149 percent, doubling sorghum yields – and also correlating with higher mineral nutrients in sorghum.[124] Heirloom bean landraces have similarly been found to contain higher nutrient contents than modern varieties.[125]

Symbiotic associations also result in more resistant plants, particularly in low-fertility soils. For example, heirloom bean landraces from Spain were found to adapt well to dry conditions,[126] and native corn outcompeted hybrid variants in taking up

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[114] Ashley Shade, Marie-Agnès Jacques, and Matthieu Barret, "Ecological patterns of seed microbiome diversity, transmission, and assembly," *Current Opinion in Microbiology* 37 (2017).

[115] Kusam Lata Rana et al., "Biodiversity, phylogenetic profiling and mechanisms of colonization of seed microbiomes," in Trends of microbial biotechnology for sustainable agriculture and biomedicine systems: Diversity and functional perspectives. Elsevier, Amsterdam (2020), pp. 99–126

[116] Pablo R Hardoim et al., "Dynamics of seed-borne rice endophytes on early plant growth stages," *PLoS ONE* 7, no. 2 (2012).

[117] Stephanie Klaedtke et al., "Terroir is a key driver of seed-associated microbial assemblages," *Environmental Microbiology* 18, no. 6 (2016).

[118] Klaedtke et al, *supra* note 117

[119] B. A. D. Hetrick, G. W. T. Wilson, and T. C. Todd, "Mycorrhizal response in wheat cultivars: relationship to phosphorus," *Canadian Journal of Botany* 74, no. 1 (1996).

[120] Xiaoke Xing et al., "Mutualism breakdown in breadfruit domestication," *Proceedings of the Royal Society B: Biological Sciences* 279, no. 1731 (2012).

[121] E. Toby Kiers, Mark G. Hutton, and R. Ford Denison, "Human selection and the relaxation of legume defences against ineffective rhizobia," *Proceedings of the Royal Society B: Biological Sciences* 274, no. 1629 (2007), pp. 3119–3126.

[122] Sangabriel-Conde et al., *supra* note 104.

[123] Mycorrhiza root colonization refers to fungi colonizing the plant's root microbiome, forming a mycorrhizal symbiosis. The fungi provide vital mineral nutrients, while plants return the favor by providing fixed carbon. The exchange of nutrients is also vital for plants' defense mechanisms against abiotic (high temperature, water scarcity, salinity) and biotic (pathogen) stress factors, see Leonie H. Luginbuehl and Giles E. D. Oldroyd, "Understanding the arbuscule at the heart of endomycorrhizal symbioses in plants," *Current Biology* 27, no. 17 (2017).

[124] Adam B. Cobb et al., "The role of arbuscular mycorrhizal fungi in grain production and nutrition of sorghum genotypes: enhancing sustainability through plant-microbial partnership," *Agriculture, Ecosystems & Environment* 233 (2016).

[125] Tugce Celmeli et al., "The nutritional content of common bean (*Phaseolus vulgaris* L.) landraces in comparison to modern varieties," *Agronomy* 8, no. 9 (2018).

[126] P. A. Casquero et al., "Performance of common bean (*Phaseolus vulgaris* L.) landraces from Spain in the Atlantic and Mediterranean environments," *Genetic Resources and Crop Evolution* 53, no. 5 (2006).

symbiotic and direct phosphorus.[127] However, plant varieties react very individually.[128] Due to mycorrhiza symbiosis, the productivity and sensual quality of in-situ cultivated landraces can be addressed more efficiently and inclusively by agricultural practices that are beneficial for arbuscular mycorrhiza fungi, such as omitting pesticide usage, avoiding soil mechanization, and inoculating the plants with arbuscular mycorrhiza fungi. Interestingly, landraces have been found to react more positively to the inoculation of arbuscular mycorrhizal fungi than genetically modified hybrid corn, which responded negatively.[129]

Higher nutrient availability in soils results in less plant–microbial symbiosis.[130] For example, in nutrient-rich environments under the usage of mineral fertilizers, plants downregulate their symbiosis[131] and stop interacting with arbuscular mycorrhiza fungi.[132] Over the last centuries, this phenomenon has been found to result in plants losing their ability to form symbioses with beneficial fungi.[133]

To maintain and promote plants forming symbiotic ties with beneficial microorganisms and to enhance plants' resistance, yields and nutritive values, it is essential to revive TEK-based farming systems and the indigenous heterogenous seeds applied in such systems. In the next section, we look at one such TEK-based farming system, namely, "natural farming" (NF), which conserves both seed and soil (microbial) diversity, leading to enhanced farmers' profits, improved soil health, and an increase in agrobiodiversity. The rapid adoption of these farming systems and the associated adoption of heterogenous seeds across India (and beyond) calls into

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[127] Sangabriel-Conde et al., *supra* note 104.

[128] For example, landraces of durum wheat created fewer symbionts with fungi in less fertile soil conditions. Walid Ellouze et al., "Potential to breed for mycorrhizal association in durum wheat," *Canadian Journal of Microbiology* 62, no. 3 (2016). However, no differences in symbionts of durum landraces and modern cultivars were found, Petronia Carillo et al., "Biostimulatory action of arbuscular mycorrhizal fungi enhances productivity, functional and sensory quality in 'Piennolo del Vesuvio'cherry tomato landraces," *Agronomy* 10, no. 6 (2020).

[129] Diana Marcela Morales Londoño et al., "Landrace maize varieties differ from conventional and genetically modified hybrid maize in response to inoculation with arbuscular mycorrhizal fungi," *Mycorrhiza* 29, no. 3 (2019); Tilal Abdelhalim, Ramia Jannoura, and Rainer Georg Joergensen, "Arbuscular mycorrhizal dependency and phosphorus responsiveness of released, landrace and wild Sudanese sorghum genotypes," *Archives of Agronomy and Soil Science* (2019).

[130] Robin van Velzen et al., "Comparative genomics of the nonlegume Parasponia reveals insights into evolution of nitrogen-fixing rhizobium symbioses," *Proceedings of the National Academy of Sciences* 115, no. 20 (2018); J. U. Regus et al., "Nitrogen deposition decreases the benefits of symbiosis in a native legume," *Plant and Soil* 414, no. 1–2 (2017).

[131] Luisa Lanfranco, Valentina Fiorilli, and Caroline Gutjahr, "Partner communication and role of nutrients in the arbuscular mycorrhizal symbiosis," *New Phytologist* 220, no. 4 (2018).

[132] Gijsbert D. A. Werner et al., "Symbiont switching and alternative resource acquisition strategies drive mutualism breakdown," *Proceedings of the National Academy of Sciences* 115, no. 20 (2018).

[133] Maximilian Griesmann et al., "Phylogenomics reveals multiple losses of nitrogen-fixing root nodule symbiosis," *Science* 361, no. 6398 (2018).

question the rationale and assumptions underlying the DUS criteria that have been employed to incentivize the creation of uniform plant varieties.

D. TRADITIONAL ECOLOGICAL KNOWLEDGE AND AGROBIODIVERSITY: LESSONS FROM THE NATURAL FARMING MOVEMENT IN INDIA

I. *Traditional Ecological Knowledge and Agrobiodiversity*

Traditional Ecological Knowledge (TEK) has been defined as a "cumulative body of knowledge, practices, and beliefs, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment."[134] In TEK-based farming systems, plant genetic material and human knowledge co-evolve in close adaptation to climatic and cultural changes. This essentially means that various TEK-based farming systems have emerged independently across various parts of the globe.[135] Nonetheless, TEK systems do follow certain basic principles, giving significant importance to the autonomy of farmers[136] (local inputs only, on-farm nutrient recycling, saving seeds)[137] and their knowledge, which is verified season after season.[138] Since TEK-based farming systems presuppose and preserve the functioning of self-sustaining ecosystems, they are also described as agroecological farming systems.[139] Unlike conventional farming systems that rely heavily on uniformity and stability, diversity (in seeds, crops, soil microbes etc.) is the lifeblood of agroecological and TEK-based farming systems.

Locally selecting, multiplying, saving, improving and exchanging seeds with desirable traits – such as stress resilience, hardiness, taste and yield[140] – has returned an astounding heterogeneity of planting materials that are genetically non-uniform,

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[134] Fikret Berkes, "Traditional ecological knowledge in perspective," *Traditional Ecological Knowledge: Concepts and Cases* 1 (1993), p. 3.

[135] Dunja Mijatović et al., "The role of agricultural biodiversity in strengthening resilience to climate change: towards an analytical framework," *International Journal of Agricultural Sustainability* 11, no. 2 (2013).

[136] Peter M. Rosset and Maria Elena Martínez-Torres, "Rural social movements and agroecology: context, theory, and process," *Ecology and Society* 17, no. 3 (2012).

[137] Thierry Bonaudo et al., "Agroecological principles for the redesign of integrated crop-livestock systems," *European Journal of Agronomy* 57 (2014), p. 49.

[138] Fikret Berkes and Nancy J Turner, "Knowledge, learning and the evolution of conservation practice for social-ecological system resilience," *Human Ecology* 34, no. 4 (2006).

[139] Charles Francis et al., "Agroecology: The ecology of food systems," *Journal of Sustainable Agriculture* 22, no. 3 (2003).

[140] Peter H. Thrall et al., "Evolution in agriculture: the application of evolutionary approaches to the management of biotic interactions in agro-ecosystems," *Evolutionary Applications* 4, no. 2 (2011).

variable and diverse.[141] Such planting materials are characterized by a particularly high within-variety diversity (intra-varietal genetic diversity).[142] They adapt year by year to local climatic conditions and soil properties. Saved heterogenous seeds, therefore, lead to more robust plants.[143]

Apart from yielding diverse plant genetic material, agroecological practices contribute to stable ecosystems.[144] The more diverse the in-soil living organisms, the better functioning are ecosystem services such as the cycling of vital nutrients for plant growth, regulation of water supply and food webs controlling pests.[145] Together, seed and soil biodiversity constitute the backbone of TEK-based farming systems. We explore this further in the context of the NF movement in India.

II. *TEK and the Natural Farming Movement in India*

Natural farming is an agroecological farming system based on the TEK of India.[146] Like most TEK-based farming systems, NF considers seed diversity and healthy soil as being fundamental prerequisites for efficient and sustainable crop cultivation.[147] Over the last decade, NF methods in India have rapidly gained popularity and momentum due to their positive impact on overall farm resilience, particularly by rehabilitating degraded soils[148] and increasing farmer profits.

As an aftermath of the Green Revolution in India, in the late twentieth century, vast soil resources were significantly degraded from the intensive usage of pesticides,

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[141] J. Cebolla-Cornejo, S. Soler and F. Nuez, "Genetic erosion of traditional varieties of vegetable crops in Europe: tomato cultivation in Valencia (Spain) as a case study," *International Journal of Plant Production* 1, no. 2 (2012).

[142] Mathieu Thomas et al., "On-farm dynamic management of genetic diversity: the impact of seed diffusions and seed saving practices on a population-variety of bread wheat," *Evolutionary Aplications* 5, no. 8 (2012).

[143] A. Ficiciyan, J. Loos, S. Sievers-Glotzbach, and T. Tscharntke, "More than yield: ecosystem services of traditional versus modern crop varieties revisited," *Sustainability* 10, no. 8 (2018), p. 2834.

[144] While the functioning of ecosystems increases with the diversity of organisms, beyond a certain level of diversity, no additional functions are provided. However, the stability of the ecosystem increases constantly with increasing diversity, see Allan Konopka, "What is microbial community ecology?," *The ISME Journal* 3, no. 11 (2009).

[145] Cameron Wagg et al., "Soil biodiversity and soil community composition determine ecosystem multifunctionality," *Proceedings of the National Academy of Sciences* 111, no. 14 (2014).

[146] Several practices in Natural Farming (that are still used in the present day) have been documented in the ancient Vedic texts of India dating back to 3000 BC–1000 BC, Vedic (*Rigveda*, *Atharvaveda*) and Ayurvedic texts (*Charaka Samhita*, *Sushruta Samhita*): N. Srikanth, Devesh Tewari and A. Mangal, "The science of plant life (Vriksha Ayurveda) in archaic literature: An insight on botanical, agricultural and horticultural aspects of ancient India," *World Journal of Pharmacy and Pharmaceutical Sciences* 4, no. 6 (2015).

[147] Jianli Liao et al., "Natural farming improves soil quality and alters microbial diversity in a cabbage field in japan," *Sustainability* 11, no. 11 (2019).

[148] Jo Smith et al., "Potential yield challenges to scale-up of zero budget natural farming," *Nature Sustainability* 3, no. 3 (2020), pp. 247–252.

mineral fertilizers and soil mechanization.[149] The NF practices support the ecological recovery of soil functions by using farming principles that revive, enhance, and protect the soil's ecosystem functions, such as better nutrient provision.[150] These functions are supported by farmer-made biostimulant preparations[151] using local materials and agricultural waste.[152] Healthy soils allow farmers to cut dependencies on expensive inputs (e.g. mineral fertilizers, seeds, and pesticides),[153] thereby reducing costs and increasing farmer profits. This scenario inspired the name "zero budget natural farming" (ZBNF).[154]

Due to their success, NF practices have spread rapidly throughout India and are recognized as the "largest 'experiment' in agro-ecology in the world."[155] The UN Food and Agriculture Organization (UN FAO) has defined ZBNF as simultaneously a set of farming methods and as a grassroots peasant movement.[156] Natural farming has been adopted by several Indian states such as Andhra Pradesh, Himachal Pradesh, Gujarat, Haryana, Karnataka, and Kerala, with Andhra Pradesh implementing its NF program at a mass scale. According to the Andhra Pradesh government, as of March 2020, roughly 620,000 farmers (10.5 percent of all

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[149] Raj Patel, "The long green revolution," *The Journal of Peasant Studies* 40, no. 1 (2013).

[150] Such practices include:

(i) The usage of fewer pesticides and mineral fertilizers, Klaus Birkhofer et al., "Long-term organic farming fosters below and aboveground biota: Implications for soil quality, biological control and productivity," *Soil Biology and Biochemistry* 40, no. 9 (2008); Yi Yang et al., "Soil carbon sequestration accelerated by restoration of grassland biodiversity," *Nature Communications* 10, no. 1 (2019); Martin Hartmann et al., "Distinct soil microbial diversity under long-term organic and conventional farming," *The ISME Journal* 9, no. 5 (2015)

(ii) Avoiding tillage, María Jesús I Briones and Olaf Schmidt, "Conventional tillage decreases the abundance and biomass of earthworms and alters their community structure in a global meta-analysis," *Global Change Biology* 23, no. 10 (2017)

(iii) Providing high-quality sources of nutrients to soil organisms, Sören Thiele-Bruhn et al., "Linking soil biodiversity and agricultural soil management," *Current Opinion in Environmental Sustainability* 4, no. 5 (2012).

[151] Patrick du Jardin, "Plant biostimulants: definition, concept, main categories and regulation," *Scientia Horticulturae* 196 (2015).

[152] M. S. Nemagoudar et al., "Isolation and characterization of microflora in beejamrutha," *Karnataka Journal of Agricultural Sciences* 27, no. 2 (2014); M. N. Sreenivasa, Nagaraj Naik and S. N. Bhat, "Beejamrutha: A source for beneficial bacteria," *Karnataka Journal of Agricultural Sciences* 22, no. 5 (2010); R. J. Patel et al., "Growth of mango (*Mangifera indica* L.) rootstocks as influenced by pre-sowing treatments," *Journal of Applied and Natural Science* 9, no. 1 (2017), p. 585.

[153] S. R. Devarinti, "Natural farming: eco-friendly and sustainable?" *Agrotechnology* 5, no. 2 (2016).

[154] Ashlesha Khadse et al., "Taking agroecology to scale: The zero budget natural farming peasant movement in Karnataka, India," *The Journal of Peasant Studies* 45, no. 1 (2018).

[155] Smith et al., *supra* note 148.

[156] Food and Agriculture Organization of the United Nations, "Zero Budget Natural Farming in India," (2016). www.fao.org/3/a-bl990e.pdf (last accessed June 06, 2021).

farmers) were enrolled in the program.[157] Himachal Pradesh aimed to convert the entire state to NF by 2022.[158] Civil society and several NF movements led by non-government organizations (NGOs) have also spread to states such as Karnataka, Tamil Nadu, and Maharashtra.[159]

Several NGOs, including the International Association for Human Values (IAHV) and the Art of Living Foundation (AOLF), are also actively engaged in imparting education in NF under the government's *Paramparagat Krishi Vikas Yojna* (PKVY) (translated as "scheme for the promotion of traditional agriculture"). In March 2020, the Indian government declared a new sub-mission to specifically promote the adoption of NF under the name *Bhartiya Prakritik Krishi Padhati* (BPKP) (translated as "Indian natural farming method"').[160] These schemes are sub-components of India's "Soil Health Management Scheme" under the "National Mission of Sustainable Agriculture," which "aims to develop sustainable models of organic farming through a mix of traditional wisdom and modern science."

Although research on the impact of NF on farm yields has not been consistent across states, the overall success and rising popularity of NF results from a combination of factors. These include widespread efforts by various individuals (notably, Subhash Palekar) and NGOs such as the AOLF, the Sri Sri Institute for Agricultural Sciences and Technology Trust (SSIAST), Kheti Virasat Mission, BAIF, IAHV, LiBird, and others to educate – or reeducate – farmers on the benefits of TEK and agrobiodiversity, thus raising farmers' profits and reducing costs while improving the soil health and the personal health of farming families that have adopted NF in recent years.[161] Proponents of NF also emphasize its ability to revive and improve

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[157] Vineet Kumar, "Indian states step up natural farming adoption," (2020), www.downtoearth.org.in/blog/agriculture/indian-states-step-up-natural-farming-adoption-73281(last accessed June 01, 2021).

[158] Kuamr, *supra* note 157.

[159] Since 2016, NGOs such as the Sri Sri Institute for Agricultural Sciences and Technology (SSIAST) have trained over 4000 farmers in NF in Andhra Pradesh alone. See International Business Times, "Heartwarming success story of how the AOL helped small farmers make big profits in drought-hit Kurnool," International Business Times, 2017, www.ibtimes.co.in/heartwarming-success-story-how-aol-helped-small-farmers-make-big-profits-drought-hit-kurnool-754817 (last accessed June 01, 2021).

[160] https://niti.gov.in/natural-farming-niti-initiative (last accessed June 01, 2021).

[161] Interviews with Indian farmers who have adopted NF within the last decade revealed that since the adoption of NF, their farm soil had become much more fertile and was giving excellent yields, including for indigenous and heterogenous seeds of ancient rice, wheat, millet and pulses. (Online interview with Mr. Yash Mishra, February and March 2021). Other farmers interviewed said that their own health, as well as the health of the entire family, has improved since they migrated to NF. "We are now happy to bring our children to the fields and let them play there while we do our daily farm chores. Earlier, we were not happy to do this because of the chemicals." Interview with farmers in Andhra Pradesh, Kurnool region, February, 2021. See also, University of Leeds, "Model Farms and Farmers in Seva," 2019, https://idip.leeds.ac.uk/2019/07/25/model-farms-and-farmers-in-seva/ (last accessed June 01, 2021). There is also the story of an award-winning red chilli farmer in Andhra Pradesh who attributes his success to his decision to migrate to NF in 2016 (International Business Times, "Heartwarming success story

local agrobiodiversity, not only in the form of indigenous seeds but also by helping to revive indigenous cattle breeds and preventing their extinction, while enhancing soil microbial diversity.

III. *Seed Biodiversity in TEK and Natural Farming*

The cultivation of local varieties of indigenous and heterogeneous seeds lies at the heart of NF, serving as the prerequisite for food security and sustainability vis-à-vis the triple bottom line: people, planet and profits. The high adaptability and hardiness exhibited by landraces to their environment over an extended period allow for low-cost and low-input farming.[162] Migrating to NF gradually reduces farmers' dependence on market-purchased "uniform" and "stable" seeds, as farmers rely on (and prefer) indigenous heterogenous seeds that perform better and can also be saved and exchanged without cost. The social practices of seed sharing and exchange further support the diversification of seed material over time,[163] facilitating agrobiodiversity conservation as well as informal (farmer-led) seed innovations.

In addition to conserving knowledge on diversities and traits, NF in India also includes knowledge of how to enhance the germination rate of indigenous seeds for better plant vitality and stress resistance.[164] For example, the seed stimulant preparation called Angara or Bheej-Amrut (or Beejamrut) is derived from Indian TEK texts.[165] Composed of cow manure, water, limestone and local soil,[166] the preparation stimulates plant growth. Farmers report negligible seed mortality rate, improved seedling length and vigor as well as enhanced seed germination rates.[167]

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of how the AOL helped small farmers make big profits in drought-hit Kurnool," www.ibtimes.co.in/heartwarming-success-story-how-aol-helped-small-farmers-make-big-profits-drought-hit-kurnool-754817 (last accessed June 01, 2021).

[162] Ficiciyan et al., *supra* note 144.

[163] Oliver T. Coomes et al., "Farmer seed networks make a limited contribution to agriculture? Four common misconceptions," *Food Policy* 56 (2015); Marco Pautasso et al., "Seed exchange networks for agrobiodiversity conservation. A review," *Agronomy for Sustainable Development* 33, no. 1 (2013); Girard and Frison, The commons, plant breeding and agricultural research: challenges for food security and agrobiodiversity (Routledge) (2018); Roy Ellen and Simon Platten, "The social life of seeds: the role of networks of relationships in the dispersal and cultural selection of plant germplasm," *Journal of the Royal Anthropological Institute* 17, no. 3 (2011).

[164] Burra Shyamsunder, "Study of traditional organic preparation beejamrita for seed treatment," *International Journal of Modern Agriculture* 10, no. 2 (2021).

[165] Sanjay Chadha, Rameshwar Ashlesha and Y. S. Paul, "Vedic Krishi: Sustainable livelihood option for small and marginal farmers," *Indian Journal of Traditional Knowledge* 11, no. 3 (2012), p. 485.

[166] N. Devakumar et al., "Microbial analytical studies of traditional organic preparations beejamrutha and jeevamrutha," *Building Organic Bridges* 2 (2014).

[167] Nemagoudar et al., *supra* note 153; Sreenivasa et al., *supra* note 153; Patel et al., *supra* note 153, p. 585.

Bheej-Amrut has been found to contain N-fixing, P-solubilizing bacteria, actinomycetes and beneficial fungi.[168]

IV. *Soil Biodiversity in TEK and Natural Farming*

The revival of seed biodiversity in TEK systems is dependent on the diversity of soil organisms, which are protected and promoted by a plethora of farming practices. For example, applying plant residues as mulch provides a nutritious carbon source for soil organisms.[169] Particularly under dry conditions, mulching can significantly increase the grain yield[170] and reduce the amount of irrigation needed, thereby also minimizing the risk of high salinity in soils connected to irrigation.[171] Similarly, low tillage is an effective practice to maintain soil health in TEK-based farming systems.[172]

Farm waste-based preparations that act like microbial plant biostimulants are also an integral part of NF. Most plant biostimulant formulations under NF are based on local (cow) manure. Specific fermentation methods transform the manure into a potent biofertilizer[173] that significantly enhances the soil's biological, physical and chemical properties.[174] For example, the formulation called Jeev-Amrut is based on (cow) manure, sugar (e.g. ripe fruits), proteins (e.g. pea flour), minerals (e.g. mineral flour), and local soil. The mix has been found to significantly increase yields,[175]

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[168] Devakumar et al., *supra* note 167.

[169] Else K Bünemann, G. D. Schwenke, and L. Van Zwieten, "Impact of agricultural inputs on soil organisms – a review," *Soil Research* 44, no. 4 (2006).

[170] Xiao-Yan Li et al., "Incorporation of ridge and furrow method of rainfall harvesting with mulching for crop production under semiarid conditions," *Agricultural Water Management* 50, no. 3 (2001).

[171] Due to less water that evaporates, the salinity level of the soil after irrigation can be lower, see Maomao Hou, Lvdan Zhu and Qiu Jin, "Surface drainage and mulching drip-irrigated tomatoes reduces soil salinity and improves fruit yield," *PLoS ONE* 11, no. 5 (2016).

[172] Maike Krauss et al., "Enhanced soil quality with reduced tillage and solid manures in organic farming – a synthesis of 15 years," *Scientific Reports* 10, no. 1 (2020); K. L. Sharma et al., "Long term evaluation of reduced tillage and low cost conjunctive nutrient management practices on productivity, sustainability, profitability and energy use efficiency in sorghum (*Sorghum bicolor* (L.) Moench)-mung bean (*Vigna radiata* (L.) Wilczek) sysem in rainfed semi-arid Alfisol" *Indian Journal of Dryland Agricultural Research and Development* 30, no. 2 (2015).

[173] These formulations are related to the ancient formulation *Panchagavya*, composed of cow dung, cow urine, milk, curd and clarified butter. *Panchagavya* resulted in enhanced root and plant growth, E. Leo Daniel Amalraj et al., "Microbiological analysis of panchagavya, vermicompost, and FYM and their effect on plant growth promotion of pigeon pea (*Cajanus cajan* L.) in India," *Organic Agriculture* 3, no. 1 (2013), p. 27.

[174] Liao et al., *supra* note 148; Suryatapa Das, Annalakshmi Chatterjee, and Tapan Kumar Pal, "Organic farming in India: a vision towards a healthy nation," *Food Quality and Safety* 4, no. 2 (2020).

[175] G. S. Manjunatha et al., "Effect of farm yard manure treated with jeevamrutha on yield attributes, yield and economics of sunflower (*Helianthus annuus* L.)," *Karnataka Journal of Agricultural Sciences* 22, no. 1 (2009); Chadha et al., *supra* note 166.

effectively control various plant pathogens[176] and increase the availability of nutrients, while decreasing the concentration of contaminants such as chloride and sulfate.[177]

The TEK-based farming systems are growing in popularity partly because of the need to recover degraded soils and to meet the growing demand for healthy, nutritious, and organic food. They are also growing out of social movements seeking to move away from high-input farming, which is considered expensive and highly vulnerable. Recent studies and developments are helping people to better understand, interpret, and improve upon ancient practices for modern application.[178] These studies point to the importance of TEK-based farming and formulations in promoting sustainable agriculture that can support the cause of enhanced food and nutritional security.

Despite its recent boom in India, TEK systems are globally endangered.[179] They are mostly used by smallholder farmers, who are outcompeted by intensive agricultural systems, or by the loss of habitats, altered lifestyles,[180] negative attitudes toward the word "traditional,"[181] and aggressive introduction of new ("improved") seed varieties, even though they do not perform consistently in marginal environments.[182] Legal and regulatory changes are urgently needed to help revive a diversity of TEK-based farming systems as possible and beneficial substitutes for conventional farming systems, particularly for marginal environments. Corresponding shifts are also needed in the educational curriculums of universities and the training of regional agricultural extension officers.

E. CONCLUSIONS AND RECOMMENDATIONS

Aano bhadra krtavo yantu vishwatah[183]

(Let noble thoughts come to me from all directions or all parts of the world)

In this paper, we have seen how the UPOV definition of variety, together with the insistence on uniformity and stability as prerequisites for the acquisition of PBRs, are

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[176] Chadha et al., *supra* note 166.

[177] Azka Iftikhar et al., "Effect of gibberellic acid on growth, photosynthesis and antioxidant defense system of wheat under zinc oxide nanoparticle stress," *Environmental Pollution* 254 (2019).

[178] Trent Brown, "Agrarian crisis in Punjab and 'Natural Farming' as a response," *South Asia: Journal of South Asian Studies* 36, no. 2 (2013).

[179] For example, in Greece and Spain, Erik Gómez-Baggethun, Esteve Corbera and Victoria Reyes-García, "Traditional ecological knowledge and global environmental change: research findings and policy implications," *Ecology and Society: A Journal of Integrative Science for Resilience and Sustainability* 18, no. 4 (2013).

[180] Eric M. Bignal and David I. McCracken, "The nature conservation value of European traditional farming systems," *Environmental Reviews* 8, no. 3 (2000), p. 152.

[181] The word was often connected to something obsolete, and in the nineteenth century it denoted simple, savage, and static characteristics, Fikret Berkes, Johan Colding and Carl Folke, "Rediscovery of traditional ecological knowledge as adaptive management," *Ecological Applications* 10, no. 5 (2000), p. 5.

[182] Catherine Odora Hoppers, "Old truths, new realities," *Africa Insight* 32, no. 1 (2002), p. 7.

[183] *Rig-Veda Samhita* 1.89 and the *Yajurveda Samhita*, available at http://literature.awgp.org/book/yajurveda/v2.76 (last accessed June 01, 2021).

grounded in legal fiction, industrial, or economic expediencies and a narrow focus on Mendelian genetics. The mainstream approach deemphasizes the influence of external factors (soil health, climate change and biotic and abiotic stresses) on seed health, performance and productivity. These "minimum standards" set up by UPOV (as well as European and national regulations that follow UPOV) assume that seeds and plant varieties that meet the DUS criteria are also better equipped to ensure high yields, meet climate challenges and enhance food security while promoting optimal innovation. Yet, emerging scientific understanding, as well as ground realities, particularly (but not exclusively) in the context of marginal farm environments and rapid climate change, suggest otherwise. They suggest that diversity and heterogeneity, rather than uniformity and homogeneity, are necessary for climate-smart, sustainable agriculture that protects seed and soil biodiversity while enhancing yields and (small) farmer incomes. Here, the presumptions underlying the CBD and the Seed Treaty – namely, that (agro)biodiversity and benefit sharing are of fundamental relevance for environmental protection and sustainable agriculture – gain fresh relevance.

Further, empirical research and several recent case studies and farmer stories suggest that not just plant breeders but also small and subsistence farmers are innovators.[184] Yet, under current IP protection regimes, their innovations (whether it be in relation to the improvement of indigenous seeds or improvements and local adaptation of TEK-based farming systems) remain without recognition or reward. This further propogates the false notion that plant breeders, and not (small) farmers, can innovate in the face of climate change. The revival as well as governmental support of TEK-based farming systems can encourage farmers, especially small and subsistence farmers, to adopt sustainable farming systems that both enhance agrobiodiversity and increase their profits. This can also help bring back dignity to the farming profession, preventing further and rapid rural–urban migration.

History has witnessed the dangers associated with discarding diversity and accepting only one line of thinking, know-how, or source of (planting) materials as being effective, efficient, or correct. The UPOV's DUS criteria have undoubtedly served their purpose of promoting industrial and formal plant breeding efforts and continue to directly contribute to farming in large landholdings. However, they have increasingly led to the rejection and discrediting of innovations emerging from farmers' fields and from agrobiodiversity that protects TEK-based farming systems. Global scientific communities cannot afford to lose this rich source of time-tested

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[184] Mrinalini Kochupillai et al., "Promoting Sustainable Seed Innovations in India: A Three Pronged Approach," Position Paper for the Indian Government (2019) [see footnote on first page of this paper for details]; "Farmers' Stories," University of Leeds, 2019, https://idip.leeds.ac.uk/category/farmers-stories/ (last accessed November 21, 2021); Clinton Beckford, David Barker and Steve Bailey, "Adaptation, innovation and domestic food production in Jamaica: Some examples of survival strategies of small-scale farmers," *Singapore Journal of Tropical Geography* 28, no. 3 (2007).

practical knowledge. In keeping with the findings of modern science, international legal regulations need to embrace, acknowledge, incentivize and reward the conservation and in-situ improvement of knowledge and materials from diverse sources to ensure sustainable innovations in seeds and plant varieties in the long run. A step in this direction can already be seen in India, and to a limited extent, also in Europe. However, a lot more needs to be done at the national as well as international levels. We highlight some trends and recommendations in the next section.

I. *Trends in Europe*

The relevance of agrobiodiversity is widely acknowledged, not only in countries of the Global South but also within Europe. In 2018, the European Union adopted Regulation (EU) 2018/848 of 30 May 2018 on organic production and the labeling of organic products (published on June 14, 2018). The regulation, for the first time, permits and encourages, inter alia, the marketing for organic agriculture of "plant reproductive material of organic heterogeneous material." It defines "organic heterogeneous material" as

> a plant grouping within a single botanical taxon of the lowest known rank which:
>
> (a) presents common phenotypic characteristics;
> (b) is characterized by a high level of genetic and phenotypic diversity between individual reproductive units, so that plant grouping is represented by the material as a whole, and not by a small number of units;
> (c) is not a variety within the meaning of Article 5(2) of Council Regulation (EC) No 2100/94 (33);
> (d) is not a mixture of varieties; and
> (e) has been produced in accordance with this Regulation.

Such heterogeneous materials do not need to fulfil the registration and certification requirements under various EU laws.[185] The regulation clarifies that "heterogeneous materials," unlike current proprietary seeds, need not be uniform or stable, and notes that based on "Research in the Union on plant reproductive material that does not fulfil the variety definition… that there could be benefits of using such diverse material… to reduce the spread of diseases, to improve resilience and to increase biodiversity."

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[185] See recitals 36 and 37 in European Parliament and the Council Regulation, "On organic production and labelling of organic products and repealing Council Regulation (EC)," Regulation (EU) 2018/848 (2018); Hanspeter Schmidt, "Regulation (EU) 2018/848 – The New EU Organic Food Law," *European Food & Feed Law Review* 14, no. 1 (2019); Matteo Petitti et al., "How to implement the organic regulation to increase production and use of organic seed. Policy recommendations for national and regional authorities," LIVESEED, booklet (2018), https://www.liveseed.eu/wp-content/uploads/2019/01/LIVESEED-FinalV2-WebInteractive-1.pdf.

Accordingly, the regulation removes the legal bar on the marketing of "heterogeneous materials" and encourages their sale for organic agriculture, thus clearing the way for the more expansive use of indigenous non-uniform seeds in agriculture. It is expected that "once the delegated [A]cts under the EU regulation are formulated, they will support the creation of markets and marketplaces facilitating trade in heterogeneous seeds, including by small farmers who have, thus far, been left out of the competition in seed markets."[186]

Further, in the context of nutrient recycling and organic fertilizers for organic agriculture, the amended recital 5a of the proposed EU regulation (which is a part of the EU Circular Economy (CE) Package) of "CE marked fertilizers" is very relevant. The recital as proposed by the EU Parliament reads: "(5a) To ensure effective use of animal manure and on-farm compost, farmers should use those products which follow the spirit of 'responsible agriculture', favoring local distribution channels, good agronomic and environmental practice and in compliance with union environmental law .... The preferential use of fertilizers produced on-site and in neighbouring agricultural undertakings should be encouraged."[187] Despite the crucial role this provision could have played in the revival of TEK-based farming that teaches farmers how to produce biostimulants and organic fertilizers on-farm, the fertilizer regulation (EU 2019/1009) dropped the proposal.[188]

The importance of locally adapted seeds has, nevertheless, been further emphasized in the Farm to Fork Strategy (2020), which states that "the Commission will take measures to facilitate the registration of seed varieties, including for organic farming, and to ensure easier market access for indigenous and locally-adapted varieties."[189] The strategy also emphasizes the need for more agroecological farming practices in the European Union.

These legal and regulatory trends suggest a small but decisive step in the direction of diversifying the marketplace for agricultural seeds. They are also in line with the

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[186] Mrinalini Kochupillai and Gregory Radick, "A wake-up call on proprietary seeds," The Hindu (2019); Alexander Wezel, Julia Goette, Elisabeth Lagneaux, Gloria Passuello, Erica Reisman, Christophe Rodier and Grégoire Turpin, "Agroecology in Europe: Research, education, collective action networks, and alternative food systems," *Sustainability* 10, no. 4 (2018), p. 1214.

[187] European Parliament, "Amendments adopted by the European Parliament on 24 October 2017 on the proposal for a regulation of the European Parliament and of the Council laying down rules on the making available on the market of CE marked fertilising products and amending Regulations (EC) No 1069/2009 and (EC) No 1107/2009 (COM(2016)0157 – C8 – 0123/2016 – 2016/0084(COD))," (2017).

[188] Regulation EU 2019/1009, "Regulation (EU) 2019/1009 of the European Parliament and of the Council of 5 June 2019 laying down rules on the making available on the market of EU fertilising products and amending Regulations (EC) No 1069/2009 and (EC) No 1107/2009 and repealing Regulation (EC) No 2003/2003 (Text with EEA relevance)," ed. European Parliament and the Council (2019).

[189] European Union, "COM(2020) 381 final: Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: A Farm to Fork Strategy for a fair, healthy and environmentally-friendly food system" (2020).

emerging scientific understanding of the urgent need to revive seed and soil microbial diversity for the sake of sustainable farming and food security. However, based on past scientific understanding, the European Union has, for decades, strictly regulated the agricultural seeds and inputs sector, outlawing active participation by farmers in the creation of agricultural seeds and associated organic fertilizers produced on-farm. These regulations have resulted in the development of specific practices and mindsets in agriculture, including among small and marginal farmers. Changing laws at the high level of the European Union will not lead immediately to a shift in local practices and mindsets.

In accordance with the principles of translational ethics and order ethics, to ensure compliance with ethically appropriate behavior (including environmentally sustainable behavior), it is necessary to ensure that legal, regulatory and governance structures incentivize the appropriate action. This can be done by, inter alia, removing perverse incentives and ensuring the necessary structural changes within existing institutional frameworks (e.g. by imparting balanced and updated education to farmers, rural agricultural extension officers and university students). This will facilitate the steering of human choices toward accomplishing more sustainable outcomes. Here, the European Union can learn from the NF movement in India, which was steered by NGOs and civil society groups but is now receiving support from the central and state governments.

II. *Reviving Agrobiodiversity and Local Food Cultures*

The revival of traditional agriculture based on indigenous and heterogenous seeds can also support the revival and nourishment of local agro-food systems (LAFS). These LAFS comprise local identity-based foods emerging from specific "territorial dynamics of agriculture, food and consumption networks."[190] By mobilizing territorial dynamics based on collective action, LAFS revive and encourage local food identity and add value to local resources, including agricultural landscapes and ecosystems, local knowledge, local social networks, food traditions and cultures, and native vegetable varieties and animal breeds.[191] While recognizing that many of the LAFS in Europe have been lost following the widespread adoption of conventional

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[190] Javier Sanz-Cañada, "Local Agro-Food Systems in America and Europe. Territorial anchorage and local governance of identity-based foods," *Culture & History Digital Journal* 5, e001 (2016) cited in Virginie Amilien and Pascale Moity-Maïzi, "Controversy and sustainability for geographical indications and localized agro-food systems: Thinking about a dynamic link," *British Food Journal* (2019).

[191] José Muchnik and Denis Sautier, "Systèmes agro-alimentaires localisés et construction de territoires," Proposition d'action thématique programmée. CIRAD, Paris, France, 46p (1998) cited in Javier Sanz-Canada, "Local Agro-Food Systems in America and Europe. Territorial anchorage and local governance of identity-based foods," *Culture and History Digital Journal* 5, no. 1 (2016).

agriculture,[192] LAFS research currently focuses on studying remaining local systems or on using the concept as an approach for analyzing local agriculture and food-specific resources. Researchers are also studying its close connection with and impact on (agro)biodiversity.[193]

The ongoing COVID-19 pandemic is a reminder of the urgent need to ensure local self-sustainable food production. Given the vast and diverse agro-climatic zones present in various regions of the world, farmers in all countries can benefit socioeconomically as well as environmentally by adopting farming systems and regulatory policies that encourage the use of local biodiversity in agriculture and incentivize farmer-level innovations with this diversity.

III. *Rethinking the DUS Test*

In the light of mounting evidence in the form of scientific research as well as on-farm experiences of small and marginal farmers, it is necessary to rethink the DUS test and identify approaches that can incentivize and promote sustainable seed innovations, not in isolation of environmental and soil interactions, but in combination with sustainable farming practices. Such innovations can include seed improvements that go hand in hand with innovative and sustainable soil management practices, manure and farm waste (nutrient) recycling methods, and/or seed storage techniques that are cost-effective and implementable in rural, low income and low-tech environments.

Beyond regulatory efforts, recent research based on extensive consultations with natural farmers in India has also recommended the adoption of technological means such as blockchain or distributed ledger technology to support the transparent and traceable sourcing of materials and know-how from farmer-innovators and ensure benefit sharing with the help of smart contracts.[194] Further research as well as funding for research and development, together with concerted international efforts, are needed to conduct more in-depth farmer interviews, build necessary prototypes and test the prototypes in real conditions to determine their acceptability, suitability and sustainability.

This is not to say that uniform varieties and the DUS test need to be done away with altogether. However, it is necessary to recognize that the unidirectional focus under current IP laws and associated regulations that incentivize and protect

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[192] Mónica Hernández-Morcillo et al., “Traditional ecological knowledge in Europe: status quo and insights for the environmental policy agenda,” *Environment: Science and Policy for Sustainable Development* 56, no. 1 (2014).

[193] Bolette Bele, Ann Norderhaug and Hanne Sickel, “Localized agri-food systems and biodiversity,” *Agriculture* 8, no. 2 (2018).

[194] Kochupillai, *supra* note 2; Kochupillai et al., *supra* note 72.

innovations only by the formal seed sector, or that permit the marketing only of certified uniform materials, is both inequitable and non-sustainable. Diversity in regulatory approaches is necessary to ensure that all potential innovators – in both the formal and informal sectors – can equitably participate in the landscape of seed innovations, while also protecting and enhancing agrobiodiversity for present and future generations.