Review article

Role of pathogens, signal recalcitrance, and organisms shifting for ecosystem recuperation. A review

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Abstract – Nature ability to adapt to ecosystem changes such as cultivation depends upon microbial interactions with plant, animals and humans. A such organisation is made possible in particular by signal exchanges, horizontal and vertical transfers of genetic material from one organism to another, the efficient use of pathogens and environment in food web interactions, the ability to metabolic modifications of shifting, and the potential to assume dormancy under unfavorable conditions. So far industrial agriculture has led to pollution and declines of biodiversity and soil carbon. The biodiversity of agricultural fields can be improved by several processes such as DNA-uptake; viruses and horizontal gene transfers; animals carrying propagules, spores, cysts and seeds from less disrupted environments; and sexual reproduction. Within weeks soil water retention capacity, nutrients availability, communication, and high biomass production is improved. In less perturbed but unfertilized, shifting cultivation systems a return to original productivities needs about 50 years.

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1. INTRODUCTION

Ecosystems, disrupted by fire, volcano eruptions, storms, flooding or to a lesser extend perturbed by faunal predation, browsing, soil compaction due to root growth or grazing, return to their initial productivity by orderly successions of herbivore-carnivore, detritus based above- and belowground food webs (Wardle, 2002). Manmade activities like ploughing, fertilization, pest management, mining, urban development or industrial waste disposals shatter agro-ecosystems and may cause carbon debts, e.g., of 702–3452 Mg CO₂ ha⁻¹ in palm- and soybean-biodiesel farms and enhance atmosphere-, ground- and water-pollution. On the other hand, it is observed that agricultural sites regain high biomass productivities much faster than traditional, unfertilized shifting cultivation systems

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where the soil is turned over with hoes for a few years’ cultivation after having areas cleared of the original steady state vegetation (Addiscott, 1995; Benckiser, 1996; FAO, 1999; Parry et al., 1999; Buckley and Schmidt, 2003; Benckiser, 2007a; Cruzen et al., 2007; Vogel and Babel, 2007; Fargione et al., 2008; Searchinger et al., 2008; Martinez-Inigo et al., 2009; Benckiser, 2010). Shifting cultivation systems need about 50 years, fertilized agricultural sites only weeks to recuperate and to return to high productivities.

About $10^{10}–10^{11}$ bacteria, sub-grouped into 6000–50,000 species, and about 200 meters fungal hyphae per gram soil care for about 5 to 80% of the annual plant nitrogen- and for about 75% of the phosphorus-demand (van der Heijden et al., 2008). Agricultural and natural biomass productivities rely on these recycler communities. Ratios between agricultural and natural biomass productivities ranging between 0.1 for Zaire and 1.07 for Benelux states reflect the quantum leaps in agricultural yields, honed during the last 5000 years, and indicate a positive influence of agricultural measures on the self-organized and host-controlled microbial activities and shifting (Esser, 1994; Benckiser, 1997; Honermeier, 2007; Valentine, 2007; Benckiser, 2007a; Ganapathy et al., 2009).

New methods, developed through the last decades, brought a variety of new insights into nature’s recuperation concepts, usually studied on the plant and animal level with recognition of microorganisms in nutrient recycling processes (Benckiser, 1997; Benckiser and Schnell, 2007; Wardle, 2002; Nannipieri et al., 2003; Kolter and Greenberg, 2006; Fuchs, 2007; von Lützow et al., 2007; van der Heijden et al., 2008; Bahn et al., 2009). Resourceful ideas have been liberated about the transitory nature of soil pore space environments and signal trans- fers, metabolic soil functioning, the self-organized and host- controlled interactions of above- and belowground food webs, environmental networks, and the remarkable abilities of hori- zontal gene transfers practicing microorganisms to form communities that conduct the portrayed life sustaining biochemical processes.

2. PERTURBATIONS, ADAPTATIONS AND SURVIVING

2.1. Information exchange

Biological information, stored in sugar-phosphate backboned genomes, replicates along template strands in opposite direction. Bases join matching bases on templates and form new identical DNA. Adaptation on environmental changes is achieved by mutations or genetic information received from outside. A crucial role in receiving genetic information from outside play DNA or RNA containing viruses and virus derived transposable (jumping) elements (TE) having genome sizes between 0.0046 (Escherichia coli, 0.3%) and 5.0 piko- grams (Zea mays, 60%; Tashiro et al., 1987; Suttle, 2005; Biemont and Vieira, 2007; Goldenfeld and Woese, 2007; Wolfe et al., 2007). Viruses, considered as gene repository and memory of a community, replicate either lysogenic in host genomes or are lytic by bursting the host cell. The error rates during replication are high and consequently the genetic diversity of viruses exceeds that of eu- and prokaryotes together. The host-integrated viral DNA is occasionally shattered, disintegrates, the host cell starts reproducing virus particles, bursts, and releases not only the virus particles but also quantitatively important amounts of nutrients into the surrounding environment. Metabolism around the virus particles resumes. Matter-, ATP- and heat-gradients emerge. The system moves away from its previously status (Rubl, 2008). Microbes, plant roots and animals are attracted. New virus-host interactions can develop. Genetic information is transported. Vehicles are besides viruses (transduction), virus RNA based transposable elements, freed and uptaken DNA (transformation), horizontal gene transfers among bacteria (conjugation) and sex among eukaryots (Goddard et al., 2005). All these genetic vehicles play a vital role in colonizing biochemical niches and in replenishing continually the genetic variability. New capabilities are obtained (Benckiser, 2007a) as documented by a sudden conversion of harmless E coli strains into hemorrhagic fever causing bacteria (Karch et al., 2005) or by a three times more often occurring virus-Staphylococcus aureus dependent pneumonia than primary viral pneumonia (Tashiro et al., 1987). Increasingly found are antibiotic resis- tant bacterial strains. Antibiotics excreted into an environment may cause species redundancy (Naeem, 1998). All these interacting activities are increasingly understood (Knight, 2004; Kolter and Greenberg, 2006; Tebbe and Schloter, 2007).

Masterly bacteria exchange up-taken viral or freed DNA among each other and are thus the most promiscuous replen- ishers of ecosystem meta-genomes. Almost daily are newly formed bacterial species detected (Vogel et al., 2009) and only recently it has been observed that animals engulf whole plastids and integrate them, though it is without doubt that sex among animals cares majorly for genetic information exchange (Rumpho et al., 2008).

Pro- and eukaryotic cells communicate not only on the gene level. A broad variety of signals like non-coding RNAs, bis-(3’–5’)-cyclic dimeric guanosine monophosphate (c-di-GMP), 2-heptyl-3-hydroxy-4 quinoline (PQS), c-adenosin monophosphate (cAMP), homoserine lactones, epigenetically changed chromatin structures, methylated or acetylated his- tones, methylated cytosine, matrix slimes (polysaccharides), extracellular products consisting of polysaccharides, proteins and nucleic acids (EPS), flagellin, environmental cues activating hundreds of hidden genes, quorum sensing (gene expression in dependency of cell density), and stochastic, mostly non-deterministic fluctuations, “noise” add to the information exchange in nature (Matusyama et al., 1992; Kessin et al., 1996; Darby et al., 2002; Rao et al., 2002; Sourijik and Berg, 2004; Mashburn and Whiteley, 2005; Branda et al., 2006; Hartmann et al., 2007; Kubicek et al., 2007; Hengge, 2009). Noise appears to be a universal information carrier, though the next state cannot fully be foreseen. Plants secrete a huge number of communicators, inter alia hormones for attracting and manipulating growth promoting microbes in their rhizospheres (Ratering et al., 2007). Biofilms formation is the visualized re- sult (Falk and Wuertz, 2007).