Preface

During the past three centuries, we have made enormous strides in our quest to understand microbes in agrarian regions. A major emphasis has been on their distribution, migration, proliferation, population density, physiological abilities, involvement in geochemical transformations of various essential nutrients, and disease causation on crops, farm animals, and humans (farmers).

During recent decades, we have understood that microbes are well distributed in the troposphere. Microbes thrive at relatively higher population density in the lower troposphere just above crops. They progressively become feeble as we climb the altitudes of the sky. Microbes in the troposphere are derived from the surface horizons of soils, natural vegetation, agricultural crops, water bodies, and animal/human activity. We may also encounter microbes in the extremes of high-altitude troposphere regions and stratosphere. Microbial ability to negotiate extreme conditions of feeble atmosphere may be of great value to us if we can transfer the traits, genetically, to symbiotic and other useful microbes found in agrarian farms. No doubt, the regular deposition of microbe-laden dust/precipitation droplets on farming belts is a natural event of significance to global agriculture. Microbes recycle naturally between agricultural soils/crops and the troposphere.

Inadvertently, we are recycling the microbes between agrarian regions and the stratosphere on a daily basis due to our ability to travel, using aircraft that fly skimming the borders of the lower stratosphere. Recently, we have learned that microbes above agricultural expanses could even be derived from the stratosphere. Or at least microbes that have successfully managed a rocket ride and stayed on the body surface of satellites or space stations.

Specific microbial species, for example, *Pseudomonas syringae, P. fluorescence*, and *P. aeruginosa*, found on aerosols, are attributed to the effect of weather systems above the Earth. They may play a role in nucleation, inducing precipitation (rain), frost, and snow.

There is a lacuna in our knowledge that must be filled to manipulate the migratory trends and paths of aerial microbes for our benefit. Microbes transit all over the globe utilizing the various aeolian processes like wind, tornadoes, hurricanes, and jet streams. Biotic agents like insects and birds aid microbial migration.

Intercontinental drifts of microbes via dust plumes/storms are a major mechanism that decides, to a certain extent, weather and precipitation patterns over agrarian expanses of other regions or even other continents. Microbes can dictate nucleation, formation of droplets, ice crystals, frost, snow, and rain. Any disturbance to a microbial load of the atmosphere and its migratory aspects is a bit risky. It has the potential to alter the agrarian environment drastically.

There are now innumerable examples that reinforce the idea that global epidemics/pandemics on crops are caused by intercontinental weather phenomena like jet streams, high-altitude winds, dust plumes, dust storms, etc. They occur in regions like the Sahara, Sahel (e.g., Harmattan), Gobi (Taklamakan), Atacama (South America), Great Plains of America, etc. Studies on crop diseases like rusts, blights, and blotches that reach epidemic proportions due to such intercontinental weather phenomena have been explained in detail. For example, dust storms aid the migration of rust fungi (e.g., *Puccinia graminis tritici*-Pgt) from Asia to Africa/West Asia, then on to the West Indies and Great Plains wheat belts. 'A dusty sky may also be a sickly sky.'

Microbial migration in the atmosphere is an important natural phenomenon of great significance to Earth systems. Microbial migration is an essential natural aspect of certain plant pathogens that cause epidemics/pandemics on crops (e.g., Fungal Rusts). Aeolian processes are intricately associated with microbial transport in air. It needs attention from farmers. Biotic factors like insects (e.g., aphids, jassids, psyllids, whiteflies, honeybees, locusts), birds, and migrating mammals aid the large-scale dissemination of microbes. They are known to disseminate plant pathogens, resulting in detrimental consequences to important food grains and horticultural crops, as well as forest plantations. There are too many examples of repeated epidemics and pandemics on crops abetted by biotic factors (i.e., vectors). Microbial migration to short distances from one plant to another within a field occurs swiftly. It is essential for the establishment of plant disease.

Microbial flora of the troposphere affects nutrient dynamics in the agroecosystem. Aerial microbes intervene at several steps during physicochemical transformations of nutrients within the agrarian region. In nature, and while we conduct practical farming, microbes negotiate soils, water bodies, and atmosphere in a continuum.

Nutrient dynamics that ensue due to aerial microbes need consideration. Atmospheric microbes mediate C-fixation, CO_2 evolution, methanogenesis, methanotrophy, and methylotrophy. Also, nitrification, i.e., N_2O and NO_2

emissions, NH_3 emission, etc. Aerial microbes are also capable of biological-N fixation that adds to organic-N in soil and microbial biomass N in the troposphere. Crop burning is practiced in food grain-generating regions. Here, the microbial metabolic processes mediate the transformation of nutrients that occur in smog, particulate matter, and mists. Microbes may detoxify smog.

Agronomic procedures have a profound impact on nutrient elements/microflora found in aerospace above a farm. Soil tillage that aerates the soil profile leads to oxidative conditions. It induces higher activity of aerobic microbes. Enhanced microbial respiration liberates more CO_2 into the agrarian atmosphere. Methanogens in rice culture zones, cattle farms, and other farm enclosures are important. Since they emit methane (CH4), which is a potent greenhouse gas. Methanogens operate under microaerophilic or anaerobic conditions. There are, of course, methanotrophs and methylotrophs, i.e., methane-oxidizers. They could be utilized to reduce CH_4 in the aerospace above crops.

The phyllosphere (i.e., crop's canopy) protrudes into the troposphere of the agrarian sky. The phyllosphere is indeed a vast area twice the size of the land surface on Earth. The phyllosphere encompasses all aerial organs of plants, like leaf lamina, branches, twigs, flowers, and pollen. They harbor and nurture microflora of diverse genetic nature and physiological abilities. Natural phenomena like gaseous exchange, foliar nutrient acquisition, entry of plant pathogens, entry of plant protection chemicals, herbicides, and growth hormones occur at the phyllosphere, i.e., leaf lamina.

Phyllosphere microbes mediate biogeochemical transformations. Phyllosphere microbes are intricately connected with nutrient cycling in agrarian regions. Phyllosphere microbes may detoxify chemicals traced on leaf lamina. Phyllosphere microbes found *in situ* or those applied could be effective biocontrol agents. Extraneous microbial biocontrol agents sprayed onto the phyllosphere do curb disease/epidemics. The phyllosphere is a vast niche with nutrient exudations where biological nitrogen fixation could be enhanced. Overall, the phyllosphere, with its microbial assemblages, is immensely important, although not so well recognized or utilized, even now. Phyllosphere microbes may also utilize exudates to synthesize novel metabolites of significance to farming.

Farmers are prone to utilize foliar mode for the supply of water and fertilizer-based nutrients. Obviously, crop foliage and microbes on it gain importance compared to soil/rhizosphere microbes. Foliage has to manage and mediate more diverse functions. Simultaneously, it has to endure harsh

troposphere conditions, if any. No doubt we have to modify the agrarian sky suitably.

We have no idea about the limits to foliar feeding of crops. Actually, in the future, geneticists and plant breeders may have to look for physiological manifestations of crop foliage. Particularly leaf area, cuticular characteristics, stomatal density, and function. Stomata are going to be burdened with greater stress. Resistance to airborne disease too, may reside in the foliage. No doubt, the phyllosphere holds the key to successful crop production.

The agrarian sky has indeed played havoc with crops' survival and productivity. The agrarian sky has bestowed disasters year after year in some regions. Agrarian sky has even forced farmers to abandon their fields and dwelling locations due to epidemics/pandemics on staple crops. The agrarian sky has mediated innumerable epidemics and pandemics on food crops. Fungal pathogens like rust fungi, blights, powdery mildews, and smuts, which devastated cereal food crops, are highly airborne. Spores drift from one region to the other due to aeolian processes like wind, jet streams, precipitation, etc.

The region just above the crop's canopy has harbored, nurtured, and helped several vectors /plant pathogen combinations. Viruses dispersed by aphids, jassids, whiteflies, and mite species are examples. Rapid aerial dispersal of the virus has devasted crops. Perhaps vector management holds the key to the successful reduction of disease severity. Reduction in insect vector population through plant protection chemicals and/or biological control is a good suggestion. Enhancing the crop's inherent resistance to viral multiplication, too, has helped to curb viral pathogens. Avoiding susceptible crop hosts/ genotypes in the vector-infested area is suggested. Inventing methods to denature virus particles is also possible. Wheat streak mosaic virus (WSMV) (Virus/*Aceria tosichella*), Cassava mosaic disease (CMD) (Virus/*Bemisia tebaci*), and Maize streak virus (MSV) (virus/ *Cicadulina* sp.) are epidemics of notable severity.

Global surveillance of major food crops for disease onset, particularly those prone to becoming virulent and causing epidemics, has been suggested. There are already a few examples, like Wheat Streak Mosaic disease, which is under aerial watch in different continents, like Australia, Asia, the Middle East, Europe, and North America. It helps to forewarn farmers about the impending disease, its spread, and potential devastation to crops in a region. Perhaps it is time we watched as many crop diseases as possible on a routine basis. Aerostats, drones, and satellite networks with facilities for spectral analysis are being utilized to survey the crops for disease.

Bacterial diseases have affected several crops of importance to farmer's exchequer. *Xanthomonas* sp. caused epidemics that have devastated several crop species. Agrarian sky mediates their spread via wind, turbulence, precipitation, splashing water droplets, and foliar sprays. Farm hygiene is a factor that induces epidemics. Citrus greening (Huanglongbing disease) caused by *Candidatus liberibacter* has reached pandemic proportions in citrus. It is spread by an aerial insect vector – a psyllid (*Diaphorina citri*).

Global farming regions have endured innumerable epidemics caused by microbial plant pathogens. Reduction in exchequer due to epidemics has been severe. For example, Wheat Stripe Rust (*Puccinia striformis*-Pst) resulted in a loss of 2.7 billion USD in 2016. In the Australian wheat belt, the Wheat streak mosaic epidemic (WSMV) resulted in a 1.27 billion A$ loss in 2014. The agrarian sky is to be blamed, to a certain extent.

Farm procedures affect microflora in aerospace. Farm procedures emit dust laden with microbes that get disseminated into the air. Agronomic procedures may disperse microbes that are detrimental to crops. Plus, the agrarian sky may spread human respiratory pathogens and others. Farm animal enclosures may harbor and disseminate pathogens that cause respiratory diseases.

There are too many aspects of global agricultural crop production that are under the influence of microbes adapted to the agrarian sky. There are ample opportunities to improve the advantages derived from aerial microbes. At the same time, deleterious effects can be bestowed on them, too. They need to be somehow curbed.

The take-home message is to look for 'Microbes in the Agrarian sky.' They are important to accomplish several ecosystem functions and achieve stable crop productivity.

Now, about the book *Microbiology of the Agricultural Sky*. There are eight highly informative chapters. They all deal with microbes of the atmosphere above the crop production regions. The first chapter provides glimpses of historical events related to microbiology as applied to global farming. Microbes in the atmosphere, particularly their distribution, diversity, and functions in the troposphere, form the central topic of Chapter 2. Aspects like microbe-mediated nucleation and its impact on crops and earth systems are highlighted.

Microbial migration in the agrarian sky is the focus of Chapter 3. Microbial migration is an essential natural phenomenon that ensures survival, dispersal, and perpetuation. Intercontinental migration or those for short distances provide opportunities for genetic intermixing of microbes. Recombinant

microbes may be useful. If they are detrimental, then we have to select them out. Chapter 4 is about the global dust storms, plumes, and mass transfer of microbes from one continent to another. Incidentally, Chapters 3 and 4 both deal in detail with the phenomenon of intercontinental dust storms, plumes, and tornadoes. Their focus is on microbes that take a ride on the storms and disperse all over the globe. It is commensurate with the great inquisitiveness shown in recent times on these topics.

Chapter 5 lists and explains various nutrient transformations that aerial microbes induce in the atmosphere. Aerial microbes affect nutrient dynamics in the agrarian regions. Aerial microbes are intricately linked with greenhouse gas emissions from agrarian fields.

Phyllosphere, which is richly endowed with microbes of diverse metabolic abilities, is the subject matter of Chapter 6. Phyllosphere microbes are vital for crop productivity. Chapter 7 deals with crop disease. Emphasis is on epidemics and pandemics caused by aerial microbes. Discussions on the intercontinental migration of microbes in relation to epidemics/pandemics are interesting. The migratory habit of aerial vectors and virus combinations that induce epidemics has been dealt with. Several examples of epidemics/pandemics that occurred during the recent past have been listed and discussed.

Overall, this treatise provides excellent information about the microbes that thrive in agricultural aerospace and their relevance to agriculture. This book will be useful to the general public. Libraries worldwide will find it to be a useful acquisition. Professors, researchers, and students in universities will like it most as a text and reference source.

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