

Contents

1	Man and the Soil–Plant–Atmosphere System	1
1.1	Introduction	1
1.2	Exercises	6
	References	6
2	Water, the Universal Solvent for Life	7
2.1	Introduction	7
2.2	Molecular Structure and Phase Change of Water	7
2.3	Surface Tension	10
2.4	Viscosity	11
2.5	The Importance of Water for Agricultural Production	12
2.6	Exercises	13
2.7	Answers	13
	References	13
3	The Soil as a Water Reservoir for Plants	15
3.1	Introduction	15
3.2	The Solid Fraction of the Soil	16
3.3	Liquid Fraction of the Soil	28
3.4	Gaseous Fraction of the Soil	40
3.5	Thermal Properties of the Soil	43
3.6	Soil Mechanics	44
3.7	Exercises	44
3.8	Answers	46
	References	47
4	Plant: The Solar Energy Collector	49
4.1	Introduction	49
4.2	Plant Anatomy	57
4.3	Water in the Plant	58
4.4	Exercises	60
4.5	Answers	60
	References	60

5 Atmosphere: The Fluid Envelope That Covers the Planet Earth	63
5.1 Introduction	63
5.2 Thermodynamic Characteristics of the Air Close to Soil Surface	65
5.3 Solar Radiation	69
5.4 Wind	79
5.5 Exercises	79
5.6 Answers	80
References	80
6 The Equilibrium State of Water in the Systems	81
6.1 Introduction	81
6.2 Thermodynamic Basis of the Soil Water Potential Concept	83
6.3 Total Potential of Water in the Soil	87
6.4 Pressure Component	90
6.5 Gravitational Component	91
6.6 Osmotic Component	93
6.7 Matric Component	94
6.8 Total Water Potential of the Plant	100
6.9 Equilibrium of the Water	102
6.10 Instruments for Soil Water Measurements	110
6.10.1 Porous Plate Funnel	110
6.10.2 The Water Tensiometer with Mercury Manometer	111
6.10.3 The Polymer Tensiometer	113
6.10.4 Electric Resistance Sensors	114
6.10.5 Richard's Pressure Membrane	114
6.10.6 Psychrometer for Air Water Potential	116
6.10.7 Psychrometer for Soil Matric Potential	116
6.10.8 Measurement of Soil Bulk Density and Water Content	117
6.10.9 Soil Bulk Density d_s	117
6.10.10 Soil Water Content (μ and θ)	121
6.11 Exercises	127
6.12 Answers	129
References	129
7 The Movement of Water in the Systems	133
7.1 Introduction	133
7.2 Water Movement in the Soil	134
7.2.1 The Darcy Equation	134
7.3 Equation of Continuity	149
7.4 Saturated Soil Water Flux	153
7.5 Non-saturated Soil Water Flux	158
7.6 Water Movement from the Plant to the Atmosphere	168
7.7 Water Movement in Open Channels and Pipes	169

12 Water Redistribution After Infiltration into the Soil	241
12.1 Introduction	241
12.2 Analysis of the Redistribution Process	241
12.3 Field Capacity	250
12.4 Exercises	252
12.5 Answers	253
References	256
13 Evaporation and Evapotranspiration: The Vapor Losses to the Atmosphere	259
13.1 Introduction	259
13.2 Evaporation Under Steady State	260
13.3 Evaporation in the Absence of a Water Table	262
13.4 Potential and Real Evaporation	264
13.5 Potential and Real Evapotranspiration	265
13.6 Measurement of the Evapotranspiration	267
13.6.1 The Thornthwaite Method	268
13.6.2 Penman Method	269
13.6.3 Penman-Monteith Method	270
13.7 Exercises	271
13.8 Answers	272
References	272
14 How Do Plants Absorb Soil Water?	275
14.1 Introduction	275
14.2 Water Availability for Plants	275
14.3 The Soil-Plant-Atmosphere System Considered as a Whole	277
14.4 Water Flux from Soil to Root	279
14.5 Available Water and Evapotranspiration	282
14.6 Exercises	287
14.7 Answers	287
References	287
15 The Water Balance in Agricultural and Natural Systems	289
15.1 Introduction	289
15.2 The Balance	289
15.3 Thornthwaite and Mather Water Balance	301
15.4 Water-Depleted Productivity	305
15.5 A Holistic View of the Agricultural Production System	306
15.6 Exercises	308
15.7 Answers	309
References	310
16 How Plants Absorb Nutrients from the Soil	313
16.1 Introduction	313
16.2 Movement of Nutrients from the Soil to the Surface of Roots	313

7.8	Exercises	171
7.9	Answers	175
	References	177
8	Soil Water as a Nutrient Solution	179
8.1	Introduction	179
8.2	Soil Solution Thermodynamics	179
8.3	Activity of an Electrolytic Solution	182
8.4	The Theory of Donnan	184
8.5	The Ionic Double Layer	186
8.6	Ionic Exchange Capacity	188
8.7	Ion Flux in the Soil	191
8.8	Solute Diffusion	192
8.9	Solute Mass Transfer	195
8.10	Solute Sources and Sinks	196
8.11	Miscible Displacement	197
8.12	Exercises	200
8.13	Answers	201
	References	201
9	Aspects of the Soil Atmosphere	203
9.1	Introduction	203
9.2	Flow of Gases in the Soil	203
9.2.1	Gas Diffusion	203
9.3	Sources and Sinks of Gases	206
9.4	Gas Mass Transfer	207
9.5	Exercises	207
9.6	Answers	208
	References	208
10	How Heat Is Propagated in the Soil	209
10.1	Introduction	209
10.2	Heat Conduction in Soils	209
10.3	Model for the Description of Temperature Changes in the Soil	211
10.4	Exercises	214
10.5	Answers	215
	References	215
11	Water Infiltration into the Soil	217
11.1	Introduction	217
11.2	Horizontal Infiltration into Homogeneous Soils	218
11.3	Vertical Infiltration into Homogeneous Soil	227
11.4	Infiltration Direction	233
11.5	Infiltration into Heterogeneous Soils	234
11.6	Some Practical Agronomic Implications	238
11.7	Exercises	238
11.8	Answers	239
	References	239

12 Water Redistribution After Infiltration into the Soil	241
12.1 Introduction	241
12.2 Analysis of the Redistribution Process	241
12.3 Field Capacity	250
12.4 Exercises	252
12.5 Answers	253
References	256
13 Evaporation and Evapotranspiration: The Vapor Losses to the Atmosphere	259
13.1 Introduction	259
13.2 Evaporation Under Steady State	260
13.3 Evaporation in the Absence of a Water Table	262
13.4 Potential and Real Evaporation	264
13.5 Potential and Real Evapotranspiration	265
13.6 Measurement of the Evapotranspiration	267
13.6.1 The Thornthwaite Method	268
13.6.2 Penman Method	269
13.6.3 Penman-Monteith Method	270
13.7 Exercises	271
13.8 Answers	272
References	272
14 How Do Plants Absorb Soil Water?	275
14.1 Introduction	275
14.2 Water Availability for Plants	275
14.3 The Soil-Plant-Atmosphere System Considered as a Whole	277
14.4 Water Flux from Soil to Root	279
14.5 Available Water and Evapotranspiration	282
14.6 Exercises	287
14.7 Answers	287
References	287
15 The Water Balance in Agricultural and Natural Systems	289
15.1 Introduction	289
15.2 The Balance	291
15.3 Thornthwaite and Mather Water Balance	301
15.4 Water-Depleted Productivity	305
15.5 A Holistic View of the Agricultural Production System	306
15.6 Exercises	308
15.7 Answers	309
References	310
16 How Plants Absorb Nutrients from the Soil	313
16.1 Introduction	313
16.2 Movement of Nutrients from the Soil to the Surface of Roots	313

16.3	Diffusion	314
16.4	Mass Flow	314
16.5	Relative Importance of Root Extension in Relation of Nutrient Absorbtion	314
16.6	Influence of Soil Physical Condition on the Transport of Nutrients	315
16.6.1	Soil Water Content	315
16.6.2	Soil Air	316
16.6.3	Soil Texture	317
16.6.4	Soil Temperature	317
16.6.5	Root System	317
16.7	Examples of Nutrient Movement in the Soil	318
16.8	Nutrient Root Absorbtion	320
16.9	Nutrient Balance	322
16.10	Use of Isotopes in Agricultural Experimentation	324
16.11	Exercises	329
16.12	Answers	329
	References	329
17	How Soil, Plant, and Atmosphere Properties Vary in Space and Time in the SPAS: An Approach to Geostatistics	331
17.1	Introduction	331
17.2	Mean (Average), Variance, Standard Deviation, and Coefficient of Variation	332
17.3	Quartiles and Moments	334
17.4	Total Amplitude and Interquartile Range	335
17.5	Skewness and Kurtosis Coefficients	335
17.6	Identification of Outliers (Discrepant Values)	336
17.7	Box Plot (Box-and-Whisker Plot)	337
17.8	Normal Frequency Distribution	337
17.9	Covariance	340
17.10	Autocorrelogram	342
17.11	Semivariogram	343
17.11.1	Models with Defined Sill (Bounded Models)	346
17.11.2	Models Without Defined Sill (Unbounded Models)	346
17.12	Ordinary Kriging: A Geostatistical Method of Interpolation	352
17.13	Pedotransfer Functions	357
17.14	Exercises	360
17.15	Answers	362
	References	363