

CONTENTS

List of tables	xix
List of figures	xxv
Preface	xxxi
Introduction	xxxiii
Acknowledgements	xxxv
Arrangement of the Compendium	xxxvii
 CHAPTER 1 CLIMATE	 1
1.1 Classification of climate	1
1.1.1 Köppens' classification	1
1.1.2 Thornthwaite's second classification	3
1.2 Phenomena relevant to agricultural meteorology	3
1.2.1 Temperature	3
1.2.1.1 Air temperatures	3
1.2.1.2 Micro-scale effects on temperature regimes	5
1.2.1.3 Soil temperature	8
1.2.1.4 Methods to influence temperature	8
1.2.1.5 Measuring methods	10
1.2.2 Wind	10
1.2.2.1 General	10
1.2.2.2 The wind profile	10
1.2.2.3 Shelter belts	12
1.2.3 Evaporation	13
1.2.3.1 Potential, actual and reference evaporation	13
1.2.3.2 Calculation of potential evaporation	14
1.2.3.3 Calculation of the actual evaporation	18
1.2.3.4 Evaporation measurements	18
1.2.3.5 Data collection	20
1.2.3.6 Checklist of required and desirable information for evaporation calculations	20
1.2.4 Dew	20
1.2.4.1 Distillation (dew rise)	21
1.2.4.2 Dew fall	21
1.2.4.3 Conditions governing dew formation	21
1.2.5 Precipitation	21
1.2.5.1 Processes and conditions influencing precipitation	21
1.2.5.2 Adjustment of rainfall records	22
1.2.5.3 Network density of rain gauges	23
1.2.5.4 Probable maximum precipitation	25
1.3 Data collection	26
1.3.1 General	26
1.3.2 Measurements and instrumentation	26
1.3.2.1 Exposure of the instruments	26
1.3.2.2 Instruments	27
1.4 References	37
 CHAPTER 2 SOIL AND LAND CLASSIFICATION	 39
2.1 Introduction	39
2.1.1 Land and soil	39
2.1.1.1 Land	39
2.1.1.2 Soil	39
2.1.2 Land and soil classification	39
2.1.2.1 Land classification	39
2.1.2.2 Soil classification	41
2.2 Parent materials of soils	41
2.2.1 Definitions	41
2.2.2 Parent material	44
2.2.2.1 Materials formed <i>in situ</i>	44
2.2.2.2 Materials transported from their place of origin	44
2.2.2.3 Organic materials	44
2.2.3 Mineralogy	44
2.2.3.1 Primary minerals	44
2.2.3.2 Clay minerals	45
2.3 Essential soil properties	46
2.3.1 Soil texture	46
2.3.1.1 Introduction	46
2.3.1.2 Textural classes	46

2.3.1.3	Classification in the field	49
2.3.1.4	Classification in the laboratory	49
2.3.2	Soil consistency	50
2.3.2.1	Introduction and description	50
2.3.2.2	Atterberg consistency limits	52
2.3.3	Soil structure	53
2.3.3.1	Introduction	53
2.3.3.2	Factors that adversely affect soil structure	53
2.3.3.3	Stability tests	53
2.3.3.4	Description of soil structure	55
2.3.4	Soil physical definitions	57
2.3.4.1	Volume, porosity, weight and density of soil	57
2.3.4.2	Soil moisture content	59
2.3.4.3	Soil moisture tension (SMT) and pF values	61
2.3.4.4	Available moisture and air capacity (drainable or non-capillary pore space)	62
2.3.4.5	Average soil physical characteristics of the major textural classes	64
2.3.5	Soil reaction	64
2.3.5.1	The pH value and its determination	64
2.3.5.2	Effect of pH on plant nutrition	65
2.3.6	Alkaline-earth carbonates in soils	65
2.3.6.1	Occurrence and consequences	65
2.3.6.2	Rating of analytical figures and field estimates	66
2.3.7	Cation exchange capacity and base saturation percentage	66
2.3.7.1	The process in general	67
2.3.7.2	The cation exchange capacity (CEC)	67
2.3.7.3	Exchangeable cations	67
2.3.8	Soil salinity and sodicity	67
2.3.8.1	Salinity	67
2.3.8.2	Sodicity	72
2.3.9	Unripened mineral and organic soils	75
2.3.9.1	Introduction	75
2.3.9.2	Physical ripening of the soil above the ultimate water-table	76
2.3.9.3	Mechanical consolidation of the underlying material	76
2.3.9.4	Some aspects of chemical ripening	77
2.3.9.5	Formulae and calculation procedures	80
2.4	Soil fertility	90
2.4.1	Introduction	90
2.4.2	Potential fertility	91
2.4.2.1	Mineral composition	91
2.4.2.2	Chemical composition of organic soil matter	91
2.4.3	Actual soil fertility	92
2.4.3.1	General	92
2.4.3.2	Nutrients	93
2.4.4	Soil-induced deficiency	96
2.4.5	Soil samples for fertility analyses	96
2.5	Soil description	96
2.5.1	Description technique	96
2.5.2	Soil horizon nomenclature	97
2.5.2.1	General	97
2.5.2.2	Master horizons	97
2.5.2.3	Transitional horizons	98
2.5.2.4	Letter suffixes	99
2.5.2.5	Figure suffixes	99
2.5.2.6	Figure prefixes	99
2.5.2.7	Revisions forthcoming	99
2.6	Diagnostic nomenclature used in the present U.S. taxonomy	105
2.6.1	Diagnostic horizons and their soil analytical parameters	105
2.6.1.1	Diagnostic surface horizons or epipedons	106
2.6.1.2	Diagnostic subsurface horizons	107
2.6.1.3	Other horizons	108
2.6.1.4	Pans	109
2.6.2	Analytical methods used to determine soil analytical parameters	110
2.6.3	FAO definitions	110
2.7	Systems of soil classification	110
2.7.1	Introduction	110
2.7.2	The U.S. soil classification system	111
2.7.2.1	The old U.S. soil classification (Baldwin, Kellog, Thorp & Smith, 1938, 1959)	111
2.7.2.2	The U.S. system of soil taxonomy (1975)	111
2.7.3	The FAO-Unesco legend for the <i>Soil Map of the World</i> (SMW), scale 1:5 million (1985)	117
2.7.4	The French classification system and the CCTA system for Africa	117
2.7.5	Relations between soil classification systems	125

2.8	The field survey	125
2.8.1	Introduction	125
2.8.2	Preparation for field-work	125
2.8.2.1	General	127
2.8.2.2	Map scale and accuracy; survey intensity	127
2.8.3	Field-work	130
2.8.3.1	Some practical indications	130
2.8.3.2	Collecting and handling of soil samples	131
2.8.4	Survey performance	133
2.8.4.1	Productive days	133
2.8.4.2	Labour	133
2.8.4.3	Staff performance	133
2.8.5	Soil survey equipment	134
2.8.6	Presentation: the map	134
2.8.6.1	Wide-scale land inventory maps	136
2.8.6.2	Technological-interpretation maps	137
2.8.7	Interpretation of aerial photographs	137
2.8.7.1	Introduction	137
2.8.7.2	Interpretation methodology	137
2.8.7.3	Use in soil surveys	138
2.8.7.4	Map scales and efficiency	139
2.9	Land suitability classifications	139
2.9.1	General	139
2.9.2	Land suitability categories according to FAO framework for land evaluation	140
2.9.2.1	Land suitability orders	140
2.9.2.2	Land suitability classes	140
2.9.2.3	Land suitability subclasses	141
2.9.2.4	Land suitability units	141
2.9.2.5	Structure of the suitability classification	142
2.9.2.6	Types of land suitability classification	142
2.9.3	Land properties to be considered	142
2.9.3.1	Land quality	142
2.9.3.2	Diagnostic characteristics and criteria	143
2.9.3.3	Limitations (deficiencies)	143
2.9.3.4	Measurement and rating of land qualities	144
2.9.3.5	Rating of soil properties	144
2.9.4	Land suitability classification according to the USBR	146
2.9.4.1	Principles of the system	146
2.9.4.2	Terminology used in the USBR system	146
2.9.4.3	Economic considerations: use of farm budgets	147
2.9.4.4	Land classes and subclasses of the USBR system	147
2.9.4.5	The USBR mapping symbol	148
2.9.4.6	Examples of USBR land classification specifications	149
2.10	Land evaluation	149
2.10.1	Definition and scope	149
2.10.2	Relevant types of land use	155
2.10.3	Preparation of a structured checklist of major and minor determinants of land utilization	156
2.10.4	Physical land evaluation	156
2.10.5	Data and assumptions underlying land evaluation	157
2.10.6	Land quality upgrading and improvement capacity	157
2.10.7	Presentation of results	158
2.10.7.1	Land classification maps in general	158
2.10.7.2	Land suitability maps	158
2.10.7.3	Technological-interpretation maps	159
2.10.7.4	Map symbols	160
2.10.7.5	Land evaluation reports	161
2.10.8	Checklist of major and minor determinants of land utilization types (an example)	161
2.10.9	Checklist of basic data for land evaluation	162
2.10.9.1	Introduction	162
2.10.9.2	Checklist	163
2.10.9.3	Explanatory notes	167
2.11	References	177
CHAPTER 3 GEODESY		179
3.1	Introduction	179
3.2	Measuring methods, instruments and accessories	179
3.2.1	Introduction	179
3.2.2	Altimetry	179
3.2.3	Angular measurements and telemetry	181

3.2.4	Instrumentation and accessories	182
3.2.5	Summary of instruments and their applications and limitations (Tables 3.2/1, 3.2/2 and 3.2/3)	182
3.2.6	Sounding	183
3.3	Organization of measurements	183
3.3.1	Planning	184
3.3.2	Calibration of instruments	184
3.3.2.1	Level	185
3.3.2.2	Theodolite	185
3.3.2.3	Electro-optical instruments	186
3.3.3	Execution of measurements	186
3.3.3.1	Altimetry	187
3.3.3.2	XY measurements	187
3.3.3.3	General instructions	188
3.4	Photogrammetry	188
3.4.1	Introduction	189
3.4.2	Basic principles	189
3.4.3	Maps from aerial photographs	189
3.4.3.1	Photo maps	190
3.4.3.2	Line maps	190
3.4.3.3	Photogrammetric data base	190
3.4.3.4	Control points	190
3.4.4	Aerial surveying	190
3.4.4.1	Principles	191
3.4.4.2	Considerations, planning	191
3.4.5	Stereoscopy	192
3.4.6	Cameras, films	193
3.4.7	Basic formulae	193
3.4.7.1	Photo scale	193
3.4.7.2	Relief displacement	194
3.4.7.3	Height determination, horizontal or X-parallax	195
3.4.8	Use of computers in photogrammetry	195
3.5	Processing of data, production of maps	195
3.5.1	Introduction	195
3.5.2	Altimetry	197
3.5.3	XY-coordinates, azimuths and distances	199
3.5.4	Methods for establishment of a geodetic network or framework	202
3.6	New developments in geodesy	202
3.6.1	Satellite positioning	202
3.6.2	Laser levelling	202
3.6.3	Data acquisition	203
3.6.4	Data processing and presentation	203
3.7	Remote sensing	203
3.7.1	Introduction	203
3.7.2	Sensors and images	204
3.7.3	Aerial photography	206
3.7.4	Multispectral scanning	208
3.7.5	Radar	210
3.7.6	Availability of remote sensing images	210
3.7.7	Image analysis and applications	210
3.7.7.1	Image (pre)processing	210
3.7.7.2	Image analysis/interpretation	211
3.7.7.3	General applications	212
3.7.8	Future developments	212
3.8	Maps: Types, scales and degrees of accuracy	213
3.9	Calculation of surfaces and volumes	213
3.9.1	Surface	213
3.9.2	Volume	213
3.10	References	000
CHAPTER 4 WATER CONTROL		
4.1	Hydraulics	215
4.1.1	General	215
4.1.1.1	Some basic conceptions	216
4.1.2	Flow formula for channels and pipes	217
4.1.2.1	Roughness coefficients and hydraulic gradients for channels and pipes	219
4.1.2.2	Maximum velocities	220
4.1.3	Hydraulic section	220
4.1.3.1	Side slopes of excavated channels	220
4.1.3.2	Shape of cross-section	220

4.1.3.3	Freeboard	221
4.1.3.4	Hydraulic design of channel networks	221
4.1.3.5	Backwater curves	221
4.1.4	Canal structures	224
4.1.4.1	General	224
4.1.4.2	Crossings	224
4.1.4.3	Weirs	225
4.1.5	Selection of structures	229
4.1.5.1	Function	229
4.1.5.2	Hydraulic characteristics	229
4.1.5.3	Range of discharge	229
4.1.5.4	Modular limit	229
4.1.5.5	Sensitivity	229
4.1.5.6	Flexibility	230
4.1.6	Pipe systems	231
4.1.6.1	Hydraulics	231
4.2	Surface water hydrology	233
4.2.1	General	233
4.2.1.1	Scope	233
4.2.1.2	The runoff process	234
4.2.1.3	Water balance	236
4.2.2	Long-period runoff data	236
4.2.2.1	Basic data	236
4.2.2.2	Means (see also 4.2.6)	236
4.2.2.3	Extreme values (see also 4.2.6)	238
4.2.3	Few runoff data, long-period rainfall data	238
4.2.3.1	Basic data	238
4.2.3.2	Yearly totals	239
4.2.3.3	Extremes	240
4.2.4	No runoff data-no rainfall data	249
4.2.5	Hydrometry	250
4.2.5.1	Preparation of survey	250
4.2.5.2	Site selection	250
4.2.5.3	Positioning of instruments and measurements	251
4.2.5.4	Instruments	251
4.2.5.5	Discharge measurements	253
4.2.5.6	Discharge calculations	255
4.2.5.7	Use of measurement results	256
4.2.5.8	Tidal effects	258
4.2.5.9	Sediment transport	260
4.2.6	Statistics, probability analysis	261
4.2.6.1	Fundamentals	261
4.2.6.2	Application of probability analysis	268
4.2.6.3	Examples	273
4.3	Groundwater hydrology	284
4.3.1	Basic concepts and occurrence	284
4.3.2	Groundwater exploration	288
4.3.2.1	Geological methods	288
4.3.2.2	Geophysical methods	288
4.3.2.3	Exploration drilling	291
4.3.2.4	Hydrologic methods	291
4.3.3	Groundwater quality	294
4.3.3.1	Physico-chemical analysis	295
4.3.3.2	Water quality classification	297
4.3.4	Quantitative groundwater flow	298
4.3.4.1	Basic concepts and equations	299
4.3.4.2	Groundwater balance	302
4.3.4.3	Determination of aquifer properties	302
4.3.4.4	Models	307
4.3.5	Groundwater exploitation	307
4.3.5.1	Water recovery methods	307
4.3.5.2	Well construction	309
4.3.5.3	Well design	309
4.3.5.4	Well completion and maintenance	312
4.3.5.5	Pumping equipment for wells	314
4.4	Drainage	316
4.4.1	Introduction	316
4.4.1.1	Definitions	316
4.4.1.2	Purpose and benefits of surface and subsurface drainage	316
4.4.2	Principles of subsurface drainage	317
4.4.2.1	Methods	317

4.4.2.2	Theory of parallel horizontal drainage	317
4.4.2.3	Vertical (or well) drainage	327
4.4.3	Principles of surface drainage	329
4.4.3.1	General	329
4.4.3.2	Surface drainage methods	329
4.4.4	Subsurface drainage criteria	333
4.4.4.1	General	333
4.4.4.2	Criteria for humid climates	334
4.4.4.3	Criteria for arid and semi-arid climates	335
4.4.5	Criteria for surface drainage	336
4.4.5.1	General	336
4.4.5.2	Drainage factor for flat areas	336
4.4.5.3	Drainage factors for sloping areas	337
4.4.5.4	Drainage factors for irrigated areas	337
4.4.6	Surveys and investigations	338
4.4.6.1	General	338
4.4.6.2	Reconnaissance survey	339
4.4.6.3	Detailed survey	339
4.4.6.4	Determination of soil hydraulic conductivity (<i>K</i> values)	340
4.4.7	Implementation of subsurface drainage systems	346
4.4.7.1	Type of system and layout	346
4.4.7.2	Materials and structures	348
4.4.7.3	Pipe drain installation	350
4.5	Irrigation	352
4.5.1	Introduction	352
4.5.2	Water quality	352
4.5.2.1	Suspended solids	352
4.5.2.2	Dissolved salts	352
4.5.2.3	Sampling of irrigation water	352
4.5.2.4	Analysis of irrigation water	353
4.5.2.5	Classification of irrigation water	357
4.5.2.6	Toxicities	357
4.5.2.7	Fertilizing value of irrigation water	359
4.5.3	Irrigation water requirements	361
4.5.3.1	Definitions and local practice	361
4.5.3.2	Crop water requirements	362
4.5.3.3	Field water requirements	366
4.5.3.4	Distribution efficiency	368
4.5.4	Field irrigation methods	375
4.5.4.1	Surface irrigation	375
4.5.4.2	Sprinkler irrigation	382
4.5.4.3	Drip irrigation	386
4.5.4.4	Subsurface irrigation	390
4.5.5	Irrigation projects	391
4.5.5.1	Water sources and their development	391
4.5.5.2	Dam site and construction	393
4.5.5.3	Flow control	394
4.5.5.4	Methods of water distribution	396
4.5.5.5	Night storage in irrigation systems	396
4.5.5.6	Layout of an irrigation system	397
4.5.6	Irrigation structures	398
4.5.6.1	Conveyance structures	398
4.5.6.2	Control and regulating structures	398
4.5.6.3	Water measurement structures	399
4.5.6.4	Escape structures	399
4.5.6.5	Other hydraulic structures	399
4.5.6.6	Pumping stations	399
4.5.6.7	Canal lining	400
4.5.7	Tertiary unit	400
4.5.7.1	Concept	400
4.5.7.2	Layout	403
4.5.7.3	Structures	405
4.6	Flood control	406
4.6.1	Dikes	406
4.6.1.1	Introduction	406
4.6.1.2	Crest elevation	406
4.6.1.3	Location of dikes	406
4.6.1.4	Dike cross-section	406
4.6.2	Channel improvements and river training	407

4.7	Operation and maintenance	407
4.7.1	Introduction	407
4.7.2	Organization of operation and maintenance	407
4.7.2.1	General	407
4.7.2.2	Components and tasks of a water management organization	408
4.7.3	Rotation	416
4.7.4	Irrigation scheduling	417
4.8	References and suggested reading	417
CHAPTER 5	LAND IMPROVEMENT	419
5.1	Land clearing	419
5.1.1	General	419
5.1.2	Land use	419
5.1.3	Condition of the area to be cleared	421
5.1.4	Methods of operation and equipment	421
5.1.4.1	Manual methods	421
5.1.4.2	Mechanical methods	421
5.1.4.3	Chemical methods	421
5.2	Land levelling	421
5.2.1	General	421
5.2.2	Need for land levelling	421
5.2.2.1	Prevention of ponding	421
5.2.2.2	Improved water distribution	422
5.2.2.3	Uniform depth to the water-table	422
5.2.2.4	Soil conservation	422
5.2.3	Factors to be considered	422
5.2.3.1	Topography	422
5.2.3.2	Soils	422
5.2.3.3	Size of the fields	422
5.2.3.4	Water supply systems	422
5.2.3.5	Hydrology	422
5.2.4	Topographical survey	424
5.2.5	Calculation of the future land surface	424
5.2.5.1	Earthwork balance and minimum volume	424
5.2.5.2	Calculation methods	424
5.2.5.3	Numerical example	428
5.2.5.4	Normal functions	428
5.2.6	Calculation of volumes	430
5.2.6.1	Methods and related errors	430
5.2.6.2	Elimination of errors	430
5.2.6.3	Numerical example and comparison of results	431
5.2.6.4	Volume calculations in the numerical example	433
5.2.7	Summary of calculation procedure	435
5.2.8	Composite operations	436
5.2.9	Implementation of land levelling	436
5.2.9.1	Control during implementation	436
5.2.9.2	Equipment	436
5.2.9.3	Contract specifications	437
5.2.9.4	Special implementation aspects	437
5.3	Reclamation of saline and sodic soils	438
5.3.1	De-salinization and de-sodification	438
5.3.2	Reclamation of saline soils	439
5.3.3	Leaching method and period	440
5.3.3.1	Re-salinization	440
5.3.4	Salinity control and leaching requirements	440
5.3.5	Estimating the leaching requirements	440
5.3.6	De-sodification	442
5.3.6.1	General	442
5.3.6.2	Divalent cations in leaching water	442
5.3.6.3	Divalent cations in the soil	442
5.3.7	Soil amendments used in reclamation of sodic soils	442
5.3.8	Reclamation of sodic soils	443
5.3.8.1	Saline sodic soils	443
5.3.8.2	Non-saline sodic soils	444
5.3.9	Reclamation and fertilizers	444
5.4	Soil improvement	445
5.4.1	Introduction	445
5.4.2	Chemical amendments	445
5.4.2.1	Correction of low pH and lime requirement	445
5.4.2.2	Correction of high pH	446

5.4.3	Physical soil improvement	446
5.4.3.1	Manual labour	446
5.4.3.2	Mechanized soil improvement	446
5.5	Soil erosion, and soil and water conservation	447
5.5.1	Definition of erosion concepts	448
5.5.2	Forms and causes of erosion	448
5.5.2.1	Water-borne erosion	451
5.5.2.2	Wind-borne erosion	451
5.5.3	Types of erosion	452
5.5.3.1	Sheet erosion	453
5.5.3.2	Micro channel or rill erosion	453
5.5.3.3	Gully erosion	453
5.5.3.4	Deposition and accumulation	454
5.5.4	Scope of soil and water conservation	454
5.5.5	Soil and water conservation on cropland	454
5.5.5.1	Lowlands (slopes up to 2%)	454
5.5.5.2	Uplands (slopes over 2%)	459
5.5.6	Soil and water conservation on pasture and rangelands	459
5.5.6.1	Pasture land	459
5.5.6.2	Rangeland	459
5.5.7	Soil/water conservation and forestry	459
5.5.8	Soil conservation on wastelands	460
5.5.9	Windbreaks (shelterbelts)	460
5.5.10	Farm operations to support soil/water conservation	460
5.5.10.1	Cropping practices	461
5.5.10.2	Tillage operations	461
5.5.10.3	Soil conditioning	462
5.5.11	Equipment	462
5.5.12	Organization, management and institutional structure	462
5.5.13	Data collection and research	462
5.6	Rural roads	463
5.6.1	Introduction	463
5.6.2	Design	463
5.6.2.1	Topographical data	463
5.6.2.2	Hydrological data	464
5.6.2.3	Soils and building materials	464
5.6.2.4	Geometry	465
5.6.2.5	Surface drainage	465
5.6.2.6	Surfacing or surface dressing	466
5.6.3	Construction	466
5.6.3.1	Testing of materials	467
5.6.3.2	Compaction of soils	468
5.6.3.3	Construction methods	468
5.6.3.4	Soil stabilization	469
5.6.4	Practical hints	469
5.7	Capacity standards for construction	469
5.7.1	General	469
5.7.2	Manual labour	469
5.7.3	Machine capacities	469
5.7.3.1	General	470
5.7.3.2	Factors governing performance	471
5.7.3.3	Performance data	472
5.7.3.4	Cost of operation	472
5.7.3.5	Land levelling	472
5.7.3.6	Subsoiling	472
5.7.3.7	Deep ploughing	473
5.7.3.8	Mixing	473
5.8	References	475
CHAPTER 6 CROP PRODUCTION		475
6.1	Introduction	475
6.1.1	Climate	475
6.1.1.1	Geographical distribution	475
6.1.1.2	Altitude	476
6.1.1.3	Day length	476
6.1.1.4	Rain	476
6.1.1.5	Sunshine	477
6.1.1.6	Temperature	477
6.1.1.7	Wind	477
6.1.1.8	Relative humidity	477

6.1.2	Soil	477
6.1.2.1	General	477
6.1.2.2	Soil cultivation	477
6.1.3	Selection of suitable crops	478
6.2	Crops	478
6.2.1	Food crops	478
6.2.1.1	Cereal crops	478
6.2.1.2	Root crops	484
6.2.1.3	Oil and protein crops	487
6.2.1.4	Sugar producing crops	495
6.2.1.5	Fruit and vegetables	498
6.2.2	Fibre-producing crops	508
6.2.2.1	Cotton (<i>Gossypium</i> spp.)	508
6.2.2.2	Jute (<i>Corchorus</i> spp.)	509
6.2.2.3	Kenaf (<i>Hibiscus cannabinus</i>)	510
6.2.2.4	Rosella (<i>Hibiscus sabdariffa</i>)	511
6.2.3	Beverage crops	512
6.2.3.1	Cocoa (<i>Theobroma cacao</i>)	512
6.2.3.2	Coffee (<i>Coffea</i> spp.)	513
6.2.3.3	Tea (<i>Camellia sinensis</i>)	514
6.2.4	Industrial crops	515
6.2.4.1	Rubber (<i>Hevea brasiliensis</i>)	515
6.2.4.2	Pyrethrum (<i>Chrysanthemum cinerariae-folium</i>)	517
6.2.4.3	Castor bean (<i>Ricinus communis</i>)	518
6.2.5	Stimulant crops	519
6.2.5.1	Tobacco (<i>Nicotiana tabacum</i>)	519
6.2.6	Fodder crops	520
6.2.6.1	Alfalfa (<i>Medicago sativa</i>)	520
6.2.6.2	Berseem (<i>Trifolium alexandrinum</i>)	521
6.2.7	Herbs and spices	522
6.3	Land use	522
6.3.1	General	522
6.3.2	Land use planning	522
6.3.3	Arable cropping	523
6.3.3.1	Shifting cultivation	523
6.3.3.2	Permanent cropping	523
6.3.4	Cropping pattern, cropping intensity and crop rotation	523
6.3.5	Anticipated cropping patterns and cropping intensities in agricultural development projects	524
6.3.6	Farming systems	525
6.4	Yields	525
6.4.1	Present and past crop yields	525
6.4.2	Yield projections	526
6.5	Water requirements (see also Subsection 4.5.4)	528
6.5.1	Agricultural considerations	528
6.5.2	Consumptive use estimates	529
6.5.3	Application of consumptive use values	530
6.5.4	'Full delta' irrigation versus under-irrigation	531
6.5.5	Excess water	531
6.5.6	Depth to water table	533
6.6	Chemical fertilizers	533
6.6.1	Introduction	533
6.6.2	Specific aspects of fertilizer usage in developing countries	533
6.6.3	Fertilizers	534
6.6.3.1	Selection of the most suitable fertilizers	534
6.6.3.2	Nitrogenous fertilizers	534
6.6.3.3	Phosphatic fertilizers	534
6.6.3.4	Phosphate-potassium compounds	536
6.6.3.5	Potash fertilizers	536
6.6.4	The use of complete mixtures	536
6.6.5	Chemical soil amendments	537
6.6.6	Trace elements	537
6.6.7	Mode of application of solid fertilizers	537
6.6.8	Estimation of fertilizer requirements	537
6.6.8.1	General	537
6.6.8.2	Feeding the soil	538
6.6.8.3	Feeding the crop	538
6.7	Manures	541
6.7.1	General information	541
6.7.2	Specific aspects of organic manuring in developing countries	541
6.7.3	Organic manures and their composition	541

6.7.4	Application rates	543	6.13	Climatic and soil requirements	567
6.8	Pest control	543	6.13.1	Annual crops	567
6.8.1	Harmful insects	543	6.13.2	Perennial crops	567
6.8.1.1	General	544	6.13.3	Summaries of the ecological requirements	567
6.8.1.2	Preventive measures	544	6.14	Labour requirements in crop production	567
6.8.1.3	Chemical control	545	6.15	Nutrition requirements and values	581
6.8.1.4	Integrated control	545	6.16	Data bases	583
6.8.1.5	Susceptibility of crops	545	6.17	International research stations that can be approached for publications, advice or plant material	583
6.8.2	Nematodes	545	6.17.1	CGIAR and CGIAR-supported centres	583
6.8.2.1	General	545	6.17.2	Non-CGIAR-supported centres	584
6.8.2.2	Preventive and natural control	545	6.17.3	Other centres	584
6.8.2.3	Chemical control	547	6.18	References and suggested reading	584
6.8.3	Rodents	547			
6.8.3.1	General	547	CHAPTER 7 PART A—ANIMAL PRODUCTION		589
6.8.3.2	Preventive control	547	7.1	Introduction	589
6.8.3.3	Chemical control	547	7.1.1	Climate	589
6.8.4	Plant diseases	547	7.1.2	Soils and other environmental factors	589
6.8.4.1	General	547	7.1.3	Vegetation	589
6.8.4.2	Preventive control	549	7.1.4	Production parameters	589
6.8.4.3	Disease spraying	549	7.1.5	Determination of age of animals by their dentition	590
6.8.4.4	Summary table	549	7.2	Cattle	590
6.8.5	Precautions when applying pesticides and fungicides	549	7.2.1	Breeds	590
6.9	Weed control	549	7.2.2	Milk and meat production	590
6.9.1	Effect of weeds on crops	551	7.3	Buffaloes	590
6.9.2	Spreading of seeds	551	7.3.1	Breeds	590
6.9.3	Weed control research	551	7.3.2	Milk and meat production	591
6.9.4	Control measures	551	7.4	Sheep and goats	591
6.9.4.1	Preventive measures	552	7.4.1	Breeds	591
6.9.4.2	Hand weeding	552	7.4.2	Wool, hair, milk and meat production	593
6.9.4.3	Weed control by submerging	552	7.5	Horses, donkeys and mules (equines)	593
6.9.4.4	Mechanical weeding	552	7.5.1	Breeds	593
6.9.4.5	Chemical weed control	553	7.6	Camels and llamas	595
6.9.4.6	Integrated weed control	553	7.6.1	Breeds	595
6.9.4.7	Biological weed control	553	7.6.2	Production	595
6.10	Mechanization	553	7.7	Pigs	595
6.10.1	Introduction	554	7.7.1	Breeds	595
6.10.2	Steps in mechanization	554	7.7.2	Production	595
6.10.3	Time and power requirements for frequent activities	556	7.8	Animal power	596
6.10.4	Cost calculation	557	7.8.1	General	596
6.11	Storage	557	7.8.2	Work capacities	596
6.11.1	Cereals, oilseeds, pulses, cassava and yams	557	7.9	Poultry	596
6.11.1.1	Losses	557	7.9.1	General	596
6.11.1.2	Moisture content	557	7.9.2	Chickens/Fowls	597
6.11.1.3	Temperature	557	7.9.3	Ducks	597
6.11.1.4	Insects and mites	558	7.9.4	Geese	597
6.11.1.5	Micro-organisms	558	7.9.5	Turkeys	598
6.11.1.6	Rodents	558	7.10	Breeding	598
6.11.1.7	Drying of produce	559	7.10.1	General	598
6.11.1.8	Selection of driers	559	7.10.2	Breeding methods	598
6.11.1.9	Drying techniques for some crops	560	7.11	Nutrition and feeding	598
6.11.1.10	Storage structures	560	7.11.1	General	598
6.11.1.11	Insecticides	560	7.11.2	Feed analysis	598
6.11.1.12	Fumigants	561	7.11.3	Digestibility	599
6.11.1.13	Fungicides	561	7.11.4	Feed evaluation	599
6.11.1.14	Rodenticides	561	7.11.5	Vitamins, minerals and trace elements	519
6.11.1.15	Storage of root crops	561	7.11.6	Additives	601
6.11.2	Fruits and vegetables	561	7.11.7	Feeds	602
6.11.2.1	Introduction	561	7.11.8	Feed requirements for ruminants and horses under (sub)tropical conditions	602
6.11.2.2	Factors affecting the deterioration in quality of fruits	561	7.11.9	Rearing schedule for calves	606
6.11.2.3	Maintaining the quality of harvested fruits	562	7.11.10	Feed requirements for pigs and poultry under (sub)tropical conditions	608
6.11.2.4	Storage practices	562	7.11.11	Water and water requirements	608
6.11.3	Vegetables	565	7.12	Forage production	609
6.12	Production of planting materials	565	7.12.1	Introduction	609
6.12.1	General	565	7.12.2	Selected grasses and legumes	610
6.12.2	Hybrids	565	7.12.3	Seed preparation	610
6.12.3	Legislation	566	7.12.3.1	Treatment of hardseededness	610
6.12.4	Breeding	566	7.12.3.2	<i>Rhizobium</i> inoculation of legumes and pelleting of seed	610
6.12.5	Variety research	566	7.12.4	Establishment	611
6.12.6	Variety index and list of varieties	566	7.12.4.1	Land clearing	611
6.12.7	Inspection and certification	566			

7.12.4.2	Cultivation	611
7.12.4.3	Sowing	611
7.12.4.4	Fertilization	611
7.12.5	Utilization and management	612
7.12.5.1	Carrying capacity and stocking rate	612
7.12.5.2	Methods of grazing	612
7.12.5.3	Health problems caused by forages	612
7.13	Animal diseases and sanitation	613
7.13.1	General	613
7.13.2	Animal diseases prevailing in the tropics	613
7.13.3	Preventive disease control	613
7.13.4	Control of tick-borne disease	613
7.13.5	Helminthic diseases	614
7.13.5.1	Parasitic gastro-enteritis of cattle, sheep and goat	622
7.13.5.2	Lungworms	626
7.13.5.3	Liver flukes	626
7.14	Nomadism	626
7.15	Housing	626
CHAPTER 7 PART B—FISHERIES		627
7.16	Introduction	627
7.17	Marine fishing	627
7.17.1	General	627
7.17.1.1	Scale of fisheries	627
7.17.1.2	Fishing grounds	627
7.17.1.3	Fishing methods	628
7.17.2	Fisheries management	628
7.17.3	Post-harvest handling and marketing	628
7.17.4	The role of women	630
7.18	Aquaculture	630
7.18.1	General aspects	630
7.18.2	Cultured organisms	630
7.18.3	Husbandry systems	631
7.18.4	Construction of fish farms	631
7.18.5	Farming systems	634
7.18.6	Farming activities	634
7.19	Glossary	636
7.19.1	Part A—Animal production	636
7.19.2	Part B—Fisheries	636
7.20	References and suggested reading	636
CHAPTER 8 FARM ECONOMICS		641
8.1	Introduction	641
8.1.1	General	641
8.1.2	Contribution of farm economics to the development process	641
8.2	Data collection	642
8.2.1	Techniques	642
8.2.2	Data required	643
8.2.2.1	Demographic data	643
8.2.2.2	Infrastructural situation	643
8.2.2.3	Land tenure	644
8.2.2.4	Crop production	644
8.2.2.5	Livestock production	645
8.2.2.6	Farmer's income	645
8.2.2.7	Off-farm income	646
8.2.2.8	Marketing	646
8.2.2.9	Credit	647
8.3	Data processing and analysis*	647
8.3.1	Introduction	647
8.3.2	Type and size of farming	647
8.3.3	Production functions	649
8.3.4	Costing	650
8.3.5	Farmer's income	651
8.4	Farm planning	651
8.4.1	Farm planning at farm level	651
8.4.2	Farm planning at government level	652
8.5	Glossary	656
8.6	References and suggested reading	656

CHAPTER 9 ECONOMIC AND FINANCIAL APPRAISAL OF PROJECTS		659
9.1	Introduction	659
9.1.1	The difference between economic and financial appraisal	659
9.1.2	Distributional aspects of project income	659
9.2	The economic appraisal	659
9.2.1	Market prices and economic values	659
9.2.2	Project costs and benefits	660
9.2.3	With and without the project	661
9.2.4	Discounting procedures	662
9.2.5	Comparison of benefits and costs	665
9.2.6	Valuation problems	667
9.2.6.1	The general issue of shadow pricing	667
9.2.6.2	Specific valuation problems	667
9.2.7	Priority ranking and maximization of project results	669
9.3	The financial appraisal	670
9.3.1	The financial appraisal in general	670
9.3.2	The financial appraisal of multi-purpose projects	671
9.4	Sensitivity and risk analysis	671
9.5	Calculation of future/present values and annuities	672
9.5.1	Introduction	672
9.5.2	Future values, individual amounts/series of unequal amounts	672
9.5.3	Future values, equal amount series	673
9.5.4	Annuities related to future values	673
9.5.5	Present values: individual amounts of money/series of unequal amounts	674
9.5.6	Present values: series of equal amounts	674
9.5.7	Annuities related to present values	674
9.6	Annex—selected interest tables	676
9.7	Glossary	688
9.8	References and suggested reading	688
CHAPTER 10 SOCIOLOGY		689
10.1	Sociology and rural development	689
10.1.1	Introduction	689
10.1.2	The inward orientation of traditional agriculture	689
10.1.3	Incorporation in modern development	689
10.1.4	Consequences of incorporation for rural communities	690
10.1.5	Consequences of incorporation at the regional and higher levels	691
10.1.6	Views on agricultural development	691
10.2	Planned development	692
10.2.1	Types of planning and actors involved	692
10.2.1.1	Types of planning	692
10.2.1.2	Actors in planning	695
10.2.2	Styles of planning and participation	695
10.2.3	Sociological contributions in the planned development process	696
10.2.3.1	Formulation of objectives	696
10.2.3.2	Analysis of the present situation	696
10.2.3.3	Plan design	697
10.2.3.4	Acceptance of the plans	698
10.2.3.5	Implementation	698
10.2.3.6	Monitoring and evaluation	698
10.3	Social aspects of physical planning	698
10.3.1	General	698
10.3.2	Sectoral planning	698
10.3.3	Levels of planning	699
10.3.4	Requirements	700
10.3.5	The procedure of physical planning	700
10.3.6	The role of the sociologist	701
10.4	Settlement and resettlement	702
10.4.1	General	702
10.4.2	The existing settlement pattern and its changes	702
10.4.3	Research prior to the planning and implementation of (re)settlement	702
10.4.4	Settlement planning	703
10.4.5	Planning of implementation	703
10.5	Reallocation of rights and resources	704
10.5.1	General	704
10.5.2	Aims and terminology	704
10.5.3	Traditional land and water rights	704
10.5.4	The genesis of reallocation of rights and resources	706
10.5.5	Tenancy reform	706

10.5.5.1	Motives	706
10.5.5.2	Risks	707
10.5.5.3	Implementation	707
10.5.6	Land reform	707
10.5.7	Land reallocation	708
10.5.7.1	Objectives	708
10.5.7.2	Legislation and farmer participation	708
10.5.8	Supplementary programmes	708
10.5.8.1	Cooperatives	708
10.5.8.2	Credit	710
10.6	The utilization of knowledge	711
10.6.1	Education for agricultural development	711
10.6.2	Agricultural extension	711
10.6.2.1	General	711
10.6.2.2	The domain of knowledge covered by 'agricultural extension'	712
10.6.2.3	The activities of the extension service and the role of the extension agent	713
10.6.2.4	Target groups for agricultural extension work	713
10.6.2.5	The preparation of an extension programme	713
10.6.2.6	Extension methods	715
10.6.3	Training for the development of agricultural institutions	717
10.6.3.1	General	717
10.6.3.2	Needs for training	717
10.6.3.3	Formulation of objectives for training	718
10.6.3.4	Training contents and training methods	719
10.6.3.5	Planning	720
10.6.3.6	Preparation of training materials	720
10.6.3.7	Conducting the training	720
10.6.3.8	Evaluation	721
10.7	References	721
10.8	Suggested reading	722
CHAPTER 11	TABLES AND SUPPORTING DATA	723
11.1	Tables	723
INDEX		731