

Index

Note: Page numbers in **bold** refer to figures in the text and those in *italics* to tables or boxes. The letter *n* following a page number indicates text in the footnotes.

- abscisic acid (ABA) 108–109
- access to water 9, 99, 100
- Acrimonium implicatum* 114
- actual evapotranspiration
 - defined 38–39
 - remotely sensed data 291–292
- adoption of technology *see* technology adoption
- aerobic rice 61–62, 109
- agricultural drought 112
- agroforestry
 - catchment experiments 225–226
 - environmental functions 223
 - manipulation of water use/root function 224–225
 - potential benefits 219
 - progress and challenges 225–227
 - rainfall-use efficiency 219–221
 - resource capture 223–224
 - semi-arid environments 226–227
 - tropical countries 226
 - water productivity 221–223
- agronomic practices
 - summary 319–321
 - see also* resource-conserving technologies and individual practices
- Alfisols 208, 209
- alkalinity
 - chemical amelioration 76, 77, 85–86
 - hazards 71–72
- allele pyramiding 118–121
- allocation of water
 - sectoral 30–31, 55, 280–283
 - Thailand 280–283
- almond trees 187
- alternate row irrigation 320
- alternate wetting and drying (AWD) 59, 60, 63
- Andes, potato production 236–237
- anthesis silking interval (ASI) 18
- antitranspirants 318*n*
- apoplastic invertase 110
- ascorbate peroxidase 109
- Asian Development Bank (ADB) 274
- Australia 16, 61, 108, 223–224
- available water 4
- available water supply (AWS) 45
- AWD *see* alternate wetting and drying
- Azadirachta indica* 224
- badia* 186–187
- banana 114
- Bangkok metropolitan area 274
- Bangladesh, floods 219
- basin efficiency 44–47
 - available water supply 45
 - beneficial depletion 44–45
 - economic 28–29
 - global current and future projections 1995 166, 174
 - impact of improved on future water productivity 174–177
 - types of river basin 46
- basins 2–3
 - beneficial water depletion 44–45
 - classification 46
 - closed 4, 46, 276–277
 - defined 5
 - land-use decisions 16–17
 - open 46
 - options for productivity improvements 9, 10–12
 - reallocation of water 15–16
 - responses to water scarcity 28–29
 - water accounting 4, 5–6
 - see also* named river basins
- basmati rice 70, 77, 78–79
- BBF *see* broad-bed and furrow

- bean, common 113, 114
 bed-planting systems 245–247, 249–250
 benefit : cost analyses 26–28
 berseem 77
 Bhakra irrigated area, India
 climate and soils 257
 water accounting 5
 watercourse characteristics 258, 259
 wheat yields 258–260
 and canal water distribution 267–268,
 269, 270
 factors affecting 260–266
 Bharatiya Agro Industries Foundation (BAIF)
 211–212
 blue water 5, 147–148
 boron 211–212
 Brazil 62
 bread wheat 193, **303–304, 306**
 broad-bed and furrow (BBF) 208, 210–211, 320
 bulk flow 315–317
 Burkina Faso 145*n*, 152–155, 158
- C₄ metabolism 57, 62, 111, 222, 318*n*
 calcium uptake 316
 CAM species 318*n*
 carbon allocation 109–110, 118
 carbon dioxide, plant uptake 315
 carbon isotope discrimination 109
 cash crops 155, 159, 279–280
 Centro Internacional de Agricultura Tropical
 (CIAT) 113, 114
 Centro Internacional de la Papa (CIP) 113, 114, 229
 cereals
 global water consumption, current and future
 172
 global water productivity, current and future
 167–174
 global yields, current and future **172**
 imports to developing countries 29, **30**, 177
 world prices 177
 see also individual cereals
 CERES water balance models 203
 CGIAR *see* Consultative Group on International
 Agricultural Research
 Chaj Doab sub-basin, Pakistan 257
 Chao Phraya basin 29, 64
 crop choice 279–280
 water allocation and efficiency 276–277, 283,
 285
- chickpea
 agroclimate **129**
 crop–water–production function **303**
 drought-tolerance breeding 134, 137, 138, 140
 early sowing 192
 integrated watershed management 208
 productivity of applied water 304, 305
 short-duration genotypes 132–133
 simulated yields and yield gap 205–206
 water management 188, 189
- chilli 208, 280
 China
 adoption of new technologies 63
 cereal water productivity 1995 167–168, **169**
 competition for water 55
 Gansu Province 155
 groundwater exploitation 54–55
 Northern plain 302–305, 306, 308
 potato production 230, 231
 rice production 54–55, 62, 63, 104, 242
 water pricing 31–32
 wheat production 302–305, 306, 308
 Yellow River 32, 55
 Zhanghe irrigation system 31–32, 55
 see also Indo-Gangetic plains
- CIAT *see* Centro Internacional de Agricultura
 Tropical
 CIMMYT *see* International Maize and Wheat
 Improvement Center
 CIP *see* Centro Internacional de la Papa
 climate change 182
 cold tolerance 108
 committed water 4
 competition for water 16, 55, 163–164, 274
 concepts 37
 Conservation Agriculture *see* resource-conserving
 technologies
 conservation tillage 155–156, 244–245, 319–320
 Consultative Group on International Agricultural
 Research (CGIAR)
 drought tolerance breeding 113–114
 ecoregional programmes 241
 germplasm screening 118–121
 see also individual CGIAR centres
 cost recovery *see* water pricing
 cotton 89–90, 294, 295
 cotton–wheat cropping 77
 cowpea 208, 209
 crassulacean acid metabolism (CAM) 318*n*
 crop breeding *see* plant breeding
 crop diversification 159, 279–280
 crop simulation modelling 205–206, 235–237
 crop yields
 global 1995 and projected future **171–172**
 rain-fed agriculture 130, 146, 150–152
 supplemental irrigation 152–154
 remotely sensed data 293–294
 saline conditions 90–92
 simulation modelling 205–206, 235–237
 trade-off with water conservation 320–321
 and water productivity 10, **12**
 and water stress 115–116, 189
 crop–water production functions
 case studies 302–305, 308
 theory 301–302
 cropping systems
 changes in 28–29
 dry areas 190–191
 saline conditions 70, 77
 water productivity 104–106
 crown pruning 225
- dams, Thailand 274, 276
 Decision Support System for Agricultural
 Technology (DSSAT) model 205–206
 deep water capture 223–224
 deficit irrigation 10, 188–189, 194–195, 305–308
 deforestation 219, 226
 delayed senescence 136, 138
 depletion of water
 beneficial 3–5, 44
 non-beneficial 44–45
 desalination 180
 developed countries
 cereal water productivity

- estimated 1995 167–168
 - impact of changing water-use efficiency 174–177
 - projected 1995–2025 168–174
- potato production 229, 230
- see also named countries*
- developing countries
 - cereal imports 29, 30, 177
 - cereal water productivity
 - estimated 1995 167–168
 - impact of changing water-use efficiency 174–177
 - projected 1995–2025 168–174
 - potato production 229–230, 231
 - see also named countries*
- digital terrain models (DTMs) 203, 205
- direct seeding 60, 63, 106–107, 320
- directed mutagenesis 118–119
- diversification, crop 159, 279–280
- drainage
 - agroforestry 221
 - reuse in irrigation 92, 96–97
 - semi-arid tropics 150, 151
- drip kits 155
- drought
 - definitions 112
 - plant responses 130, 131–132
 - semi-arid tropics 130
 - see also water stress*
- drought tolerance
 - complexity 114–116
 - crop screening 133–134
 - plant breeding
 - CGIAR programmes 113–114
 - germplasm screening 118–121
 - identifying genes for 118
 - impact of 139–140
 - inefficiencies 114–116
 - integrated strategies 140–141
 - plant traits 108–109, 114–116, 136–138
 - QTL mapping 116–118, 138–139
 - rice 58, 113
 - short-duration crops 132–133
- drought-susceptibility index (DSI) 134
- dry areas 179–180
 - additional water sources 180
 - crop improvement 113–114, 184, 190, 192–193
 - cropping patterns 190
 - deficit irrigation 305–308
 - effective water management 180–181
 - future directions and research issues 195–197
 - integrated approach to water management 183–184
 - small-scale irrigation systems 196
 - soil management 190–191
 - water scarcity 181–182
 - water-use efficient techniques 185–189, 193–195
- DSI *see* drought-susceptibility index
- DSSAT (Decision Support System for Agricultural Technology) model 205–206
- durum wheat 193, 194, 303–304, 306
- early growth vigour 138
- economic efficiency (EE) 21–22
 - crop varietal improvement 25–26
 - irrigation systems 26–28
 - net private returns 23–24
 - net social returns 24
 - river basins 28–29
 - valuation of water 23, 46–47
- economic water scarcity 2, 54
- efficiency
 - classical concepts 38–40, 47–48
 - effective 41, 42
 - fractions 42–43
 - neoclassical concepts 40–43, 48
 - net 41
- Egypt 93, 99, 187, 280
- endophytic fungi 114
- Energy Generation Authority of Thailand (EGAT) 276
- environmental issues 24–25, 33, 63–64
- estuaries, salinity 64
- Eucalyptus camaldulensis* 224
- evapotranspiration
 - actual 38–39
 - net 39
 - remotely sensed data 291–292
 - semi-arid tropics 150, 151
- exchangeable sodium percentage (ESP) 72, 91
- externalities 24, 48
- faba bean 188, 189
- Faidherbia albida* 222
- farmers
 - adoption of new technology *see* technology adoption
 - impact of water reallocation 282
 - incentives for water productivity increases 13, 277
 - interactions with irrigation management 12–15
 - options for water productivity increases 8–9, 10
 - participatory irrigation management 32
 - participatory plant breeding 120, 121
 - participatory technology development 194–195, 250–251
 - participatory watershed management 201, 208–209, 212, 214
 - resource-poor 251
 - risk perception 158
 - training 212
- fertilizer use
 - dry areas 190–191
 - semi-arid tropics 153–154, 158
 - wheat production 262, 263
- fisheries 5–6, 279
- flooding 219, 276
- flooding tolerance 111–112
- flowering, water stress 115, 316
- food security 163, 182, 240
- food-water model *see* IMPACT-WATER
- forests 217, 218–219, 226
- free markets 48–49
 - small-scale 82–84
- Gal Oya Water Management Project 27–28
- Gansu Province, China 155
- Gediz basin, Turkey 28–29
- gender 212, 214
- genetic transformation 62, 107, 108, 110, 111
- geographical information systems (GIS) 202–205, 289, 291, 293, 297

- germplasm screening 118–121
 Gini coefficient 261*n*
 GIS (geographical information systems) 202–205, 289, 291, 293, 297
 glyphosate resistance 107
 grapes 12–13
 green manures 107–108
 Green Revolution 218
 green water 5, 147–149, 157–158
 greenhouse gases 63
Grevillea robusta 222
 groundnut
 agroclimate 129
 drought-tolerance breeding 134, 137, 138, 140
 short-duration genotypes 132–133
 groundwater
 conjunctive use with surface water 32–33, 73, 74, 82, 83, 96–97, 99–100
 overexploitation 33, 54–55
 salinity 78, 82–84, 92–93
 transfers 82–84
 uptake by tree roots 93, 224
 wheat production 261, 265, 266
 groundwater–resource ratio 293
 guard cells 312–313
 gypsum 76, 77, 85–86, 211
- Hadejia–Jama'are, Nigeria 9
 Han Dao rice 62, 109
 harvest index 25–26, 109–110
 panicle 136
 Haryana state, India
 climate 72–73
 saline/alkaline groundwater 71
 salinity/alkalinity management 73–75, 76, 78–79, 80, 81, 82–85
 head–tail equity ratio 261*n*
 heat tolerance 109, 232, 234, 237
 heat-shock proteins 109
 hedgerows 220–221, 224, 225
 herbicide resistance 107
 herbicides 243, 244, 245
 Himalayas 219
 hydraulic lift 221
 hydrological drought 112
- ICARDA *see* International Centre for Agricultural Research in the Dry Areas
 ICRISAT *see* International Crop Research Institute for the Semi-Arid Tropics
 IITA *see* International Institute for Tropical Agriculture
 IMPACT-WATER model 164
 methodology, data and assumptions 164–166
 water productivity 1995–2025 167–174
 alternative scenarios 174–177
- India
 adoption of new technology 63
 Bhakra irrigated area
 canal water distribution 267–268, 269, 270
 climate and soils 257
 water accounting 5
 watercourse characteristics 258, 259
 wheat production factors 260–266
 wheat yields 258–260
 cereal productivity 1995 168, 169
 flooding 219
 potato production 230, 231
 Rajasthan irrigation district 157
 saline groundwater 71, 82–84
 salinity/alkalinity management 73–85
 salinization/desalinization cycles 72–73
 water budget simulation 202–205
 wheat production 256, 258–266
 see also Indo-Gangetic plains
 Indo-Gangetic plains
 food demand 240
 potato production 230, 236
 Rice–Wheat Consortium 241
 rice–wheat cropping 239–240
 resource-conserving technologies 241–249
 technology adoption 249, 250–251
 water savings 249–250
 water demand 240
 induced innovation theory 28
 Indus basin, Pakistan 93
 crop yield data 293–294
 hydrological data 291–293
 water productivity 294–298
 industry 9, 16, 24, 55
 INERA *see* Institut National de l'Environnement et de la Recherche Agricole
 infiltration 91, 220
 inflows 4, 8*n*
 INSTAT 145*n*
 Institut de Recherche pour le Développement (IRD) 145*n*
 Institut National de l'Environnement et de la Recherche Agricole (INERA) 145*n*
 institutional water management 29–33
 integrated on-farm water management, dry areas 183–184
 interception 220
 intercropping systems 208, 209
 internal rate of return 26–28
 International Centre for Agricultural Research in the Dry Areas (ICARDA) 179–180
 plant breeding programmes 113–114, 190, 192
 research areas 184
 supplemental irrigation research 185–186, 188–189, 194–195
 International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) 113–114
 integrated watershed management
 consortium approach 212
 farmer participation 201, 208–209
 microwatershed development 209–212
 monitoring and evaluation 212–213
 new science tools for evaluation and management 202–207
 on-farm trials 200, 201
 on-station research 207–208, 209
 Vertisol technology package 200, 201, 207
 mandate crops 127
 characterization of drought-resistance traits 136–138
 drought tolerance screening 133–134
 improvement strategies 134–136
 integrated genetic improvement strategies 140–141
 molecular breeding techniques 138–139

- short-duration genotypes 132–133
 target environments 128–130
 International Institute for Tropical Agriculture (IITA) 113, 114
 International Maize and Wheat Improvement Center (CIMMYT) 113–114
 International Potato Center (CIP) 113, 114, 229
 potato research 232–235
 SUBSTOR-Potato model 235–237
 International Rice Research Institute (IRRI) 58, 107, 113–114
 international trade 29, 30, 177
 Internet sources 312*n*, 313*n*
 invertase gene 110
 inverted-T openers 242–244
 Iran 177
 IRD *see* Institut de Recherche pour le Developpment
 IRRI *see* International Rice Research Institute
 irrigation
 agronomic practices 58–59, 60, 80–81, 319–320
 benefit–cost analyses 26–28
 canal-water distribution 99, 100, 261–263, 265–270
 deficit 188–189, 194–195, 305–308
 global water use 163
 groundwater use 32–33, 261, 293, 296
 management
 interactions with farms 12–15
 participatory 32
 re-use of drainage 96–7, 180
 saline conditions
 economic efficiency 78–81
 leaching requirement 75, 92, 94–96, 97–98
 productivity increase 81–85
 root-zone management 73–78
 water-use practices 85–86
 small-scale 155, 196
 supplemental 181, 185–186, 188–189, 192–193, 194–195
 water accounting 3–5
 water pricing 31–32, 277–278, 285
 water productivity 104–5
 definitions 9, 295–296, 298
 global current and future projections 168–170, 171–173
 options for improvement 9, 10–11
 and spatial scale 57, 58, 297–298
 water savings 58–59, 60, 64
 irrigation efficiency (IE) 20–21
 classical concept 20–21, 38–40, 47–48, 296–297
 and economic efficiency 21–22
 neoclassical concept 21, 40–43
 saline conditions 70
 isoproturon 245
 Jordan 181, 187
 karite 222
 Kenya, Machakos 145*n*
 agroforestry 220, 221, 224
 rain-fed agriculture 152–155
 rainfall patterns 150–151
 land levelling 320
 rice–wheat cropping 248, 250
 saline conditions 80–81
 land-use changes 16–17
 leaching, of salts 75, 92, 94–96, 97–98
 leaf area 138
 leaf cuticular membranes 108
 lentil 188, 189, 303, 304, 305
Leucaena leucocephala 224
 lignin 109
 line-source-sprinkler irrigation 134
 Lower Jhelum canal system, Pakistan
 canal water distribution 267–268, 269, 270
 climate and soils 257
 watercourse characteristics 258, 259
 wheat productivity factors 260–266
 wheat yields 258–260
 Machakos, Kenya
 agroforestry 220, 221, 224
 rain-fed agriculture 150–155
 rainfall patterns 150–151
 Madagascar 26, 27, 278*n*
 Mae Klong basin, Thailand 277, 285
Maesopsis emini 224
 magnesium uptake 316
 maize
 anthesis silking interval (ASI) 118
 conservation tillage 156
 global production 230
 improved watershed management 210
 nutrient uptake 316, 317
 supplemental irrigation 153–154, 305, 307
 water productivity 57, 305
 yield and water availability 150–151
 Majjia valley, Niger 224
 Malaysia, Muda irrigation scheme 59, 60
 marginal/low-quality water use 180, 247
 marker-assisted selection (MAS) 119, 139
Melia volkensii 226
 methane emissions 63
 Mexico 29, 30, 245
 microarray analysis 116, 117
 microcatchments 187
 microclimate 108, 222
 microirrigation 155
 microwatershed 209–212
 molecular biology 62, 103, 118–121, 138–139
 monsoonal climate 72–73
 montane forests 226
 Muda irrigation scheme, Malaysia 59, 60
 mulches 234–235, 242, 243, 320
 multiplier effect 46
 mungbean 79, 80
 mustard 77, 79, 80
 mutagenesis, directed 118–119
 national agricultural research systems (NARS) 192
 National Oceanic and Atmospheric Administration-Advanced Very High Resolution Radiometer (NOAA-AVHRR) satellite 291–294
 nere 222
 Niger 224
 Nigeria 9
 Nile basin, Egypt 93, 99
 nim trees 224

- nitrogen fixation 108
 nitrogen-use efficiency 108
 nitrous oxide 63
 NOAA-AVHRR satellite 291–294
 North China Plain 302–304, 306, 308
 nutrient uptake
 agroforestry 223–224
 bulk flow to roots 315–317
 nutrient-budgeting 211–212, 213

 Oregon state, USA 302–305, 307
 organic matter application 320
Oryza glaberrima 107
Oryza rufipogon 111
 outflows 3–6
 basin scale 6
 committed/uncommitted 4
 field scale 3, 4
 irrigation system 3, 5
 rice production 56–60

 Pakistan
 Indus basin 93
 crop yield data 293–294
 hydrological data 291–293
 water-productivity analyses 290, 294–298
 Lower Jhelum canal system 257
 canal-water distribution 267–268, 269, 270
 climate and soils 257
 watercourse characteristics 258, 259
 wheat productivity factors 260–266
 wheat yields 258–260, 268–270
 wheat production 256, 260–270
 panicle harvest index 136
 Parakramabahu, King of Sri Lanka 37
Parkia biglobosa 222
 partial factor productivity 22–23
 participation
 irrigation management 32
 plant breeding 121
 research and technology development 194–195, 208–209, 212, 250–251
 pearl millet
 drought tolerance breeding 134, 135, 137, 139–140
 ICRISAT target environment 128, 129
 short-duration genotypes 132
 supplemental irrigation 208, 209

 Peru
 potato production 236–237
 potato research 232–234
Phalaris minor 244, 245–246
 phosphorus uptake 316
 photosynthesis 11, 57, 62, 111, 222, 318*n*
 photosynthesis:transpiration ratio 109
 pigeonpea
 drought-tolerance breeding 134, 136, 137, 140
 ICRISAT target environment 129–130
 short-duration genotypes 132–133, 140
 sorghum/soybean intercrop 208, 209, 210
 supplemental irrigation 208, 209
 plant breeding 25–26
 drought tolerance 113–116
 impact of 139–140
 integrated strategies 140–141
 molecular methods 118–121, 138–139
 plant traits 108–109, 114–116, 136–138
 screening and selection 118–121, 133–134
 dry areas 113–114, 184, 190, 192–193
 funding 26
 interactions with management 192–193
 molecular methods 103, 110, 112, 116–121, 138–139
 potato 232–234
 productivity increase 25–26, 103, 109–111
 rice 58, 62, 113
 short-duration 110–111, 132–133
 plant traits
 drought tolerance 114–116, 136–138
 increasing production without increasing transpiration 109–111
 QTL mapping 110, 112, 116–118, 138–139
 reducing non-transpiration water use 106–107
 reducing transpiration 108–109
 salinity tolerance 58, 80, 85, 112
 waterlogging/flooding tolerance 111–112
 pollution 49*n*
 population, human 182, 240
 potassium uptake 316
 potato
 agronomic practices 234–235
 genotypic variation in water productivity 234, 235
 global production 229, 230
 heat-tolerance 232, 234
 production in developing countries 229–230, 231
 productivity simulation modelling 235–237
 yield improvements 230–231
 yield and water supply 232–234
 precision levelling 80–81
 pricing *see* water pricing
 productivity of applied water (PAW) 304–305
 and deficit irrigation 305–308
 proteomics 116, 117
 puddling 59, 247–248, 250
 Punjab Agricultural University 245–246

 quantitative trait loci (QTL) 110
 drought tolerance 116–118, 135, 136, 138–139
 rice 110, 116
 salt tolerance 112

 rainfall
 infiltration 91, 220
 interception 220
 partitioning 150, 151
 productivity 152
 variability 149–151
 rainfall-use efficiency 60, 219–221
 rain-fed agriculture
 conservation tillage 155–156
 crop genetic enhancement 131–140
 dominance of 146
 hydroclimatic challenges 149–150
 rice 54, 106, 170–174
 risks 158, 159
 soil fertility management 153–154, 158
 supplemental irrigation 152–155, 181, 185–186, 192–193
 deficit 188–189, 194–195, 305–308
 microirrigation 155

- water productivity
 - assessment 104, 152
 - global current and future projections 170, **172–173**, 174
 - yield improvement options 130, 150–152
 - yields 130, 146
 - see also* watershed management
- rain-out shelter 134
- rainwater management
 - dry environments 186
 - evaluation 207–208, 209
 - rationale for 147–149
 - saline environments 81
 - watershed scale 156–157
- raised beds 60–61, 245–247, 320
- raised-bed-furrow 247
- Rajasthan district, India 157
- Ranga Reddy district, Andhra Pradesh 208–209
- RCTs *see* resource-conserving technologies
- reallocation of water 9, 11–12, 15–17, 30–31, 55, 280–283
 - trade-offs between uses 9, 16–17
- redwood 313–314
- relative humidity 314
- remotely sensed data 299
 - crop yields 293–294
 - hydrology 291–293
- reservoir storage, global 166
- resource-conserving technologies (RCTs) 241
 - adoption and participatory development 249, 250–251
 - bed-planting systems 245–247, 249–250
 - laser levelling 248, 250
 - low-quality water use 247
 - non-puddling for rice 247–248
 - reduced tillage 244–245
 - supplemental water use 248–249
 - surface seeding 242
 - water saving 249–250
 - zero tillage 242–244
- reuse/recycling of water 38, 92, 96–97
- Rhizobium* 108
- rice
 - aerobic 61–62, 109
 - drought tolerance 58, 115–116
 - genetic transformation 62, 107, 108, 110, 111
 - germplasm improvement 58, 62, 113
 - photosynthesis:transpiration ratio 109
 - semi-dwarf trait 110
 - short duration 110–111
 - submergence tolerance 111–112
 - water stress 115–116
- rice production
 - adoption of new technologies 62–63
 - aerobic 61–62, 109
 - biotechnology 62
 - diversification to other crops 279–280
 - dry/direct seeding 60, 63, 106–107, 320
 - global 230
 - global prices, estimated and projected 177
 - global water consumption, current and future 168–170, **171**
 - global water productivity, current and future projections 167–170, **171–173**
 - global yields, current and future projections 170, **171**
 - Indus basin 294, 295
 - land preparation 59, 63
 - puddling 59, 247–248, 250
 - rain-fed 54, 106, 170–174
 - risks 279–280
 - saline/alkaline conditions 75–77, 99
 - saturated soil culture 59, 60–61
 - sustainable management 63–64
 - water availability 54–55
 - water inputs 56–57
 - water outflows 56–60
 - water productivity 57–58
 - current and future projections 167–170, **171–173**
 - see also* rice–wheat cropping
- Rice–Wheat Consortium (RWC) 241–9
- rice–wheat cropping 105
 - Indo-Gangetic plain 239–240
 - resource-conserving technologies (RCTs) adoption 249, 250–251
 - bed-planting systems 245–247, 249–250
 - laser levelling 248, 250
 - low-quality water use 247
 - non-puddling of soils 247–248, 250
 - reduced tillage 244–245
 - supplemental water use 248–249
 - water use benefits 249–250
 - zero tillage 242–244
 - saline/alkaline conditions 75–77, 247
- Rio Lerma-Chapala basin, Mexico 29
- rippers 156
- risk
 - rain-fed agriculture 158, 159
 - rice production 279–280
- river basin *see* basins
- root-zone salinity 73–78, 94–96, 98–99
- roots
 - drought-tolerance traits 138
 - hydraulic lift 221
 - pressures 314
 - pruning 224–225, 226
 - soil nutrient uptake 315–317
 - trees 221, 223–224
 - water loss 109
- row spacing/orientation 320
- runoff
 - agroforestry systems 220, 221
 - harvesting 147, 157, 205
 - reuse in irrigation 92, 96–97
 - semi-arid tropics 150, **151**
- RWC *see* Rice–Wheat Consortium
- safflower 208
- saline conditions
 - crop yield response functions 90–92
 - cropping systems 70, 77, 80
 - disposal of salts 84–85, 93, 100
 - groundwater 78, 82, 92–93
 - hazards 71–72, 91
 - Indus River basin 93
 - land levelling 80–81
 - productivity improvements 81–85
 - approaches to 69–71
 - economic 70, 78–81
 - rainwater conservation 81
 - rice production 75–77, 99, 247
 - root-zone management 73–78, 94–96, 98–99
 - seasonal cycles 72–73

- saline conditions *continued*
 soils 3, 72, 74–75, 91, 260–261
 water application modes 33, 73–75, 82, 83, 96–97, 99–100, 247
 water diversion 99–100
- salinity tolerance 80, 85
 cotton 89–90
 rice 58, 112
 threshold values 90, 91–92
 timing of water stress 79–80, 92
 wheat 79, 90, 91
- SALLUS-TERRAE model 205
- salt stress 79–80, 92
- satellite data 299
 crop yields 293–294
 hydrology 291–293
- saturated soil culture (SSC) 59, 60–61
- scale issues 2–3, 8–9, 17, 23, 297–298
- irrigation systems 57, 58, 297–298
 water accounting 3–6
 water-use efficiency 275–276
- SEBAL (surface energy-balance algorithm for land) 291–292
- sectoral water allocation 9, 11–12, 15–16, 30–31, 55, 280–283
- seed drill, inverted-T opener 242–244
- semi-arid tropics (SAT)
 climate 128, 129, 149–150, 200
 drought 128–130
 rain-fed agriculture 156
 conservation tillage 155–156
 crop genetic enhancement 131–140
 hydroclimatic challenges 149–150
 rice 54, 106, 170–174
 risk 158, 159
 soil fertility management 153–154, 158
 supplemental irrigation 152–155, 185–186, 188–189, 192–195, 305–308
 water productivity 104, 152, 170, 172–173, 174
 yield improvement options 130, 150–152
 yields 130, 146
 water scarcity 200
 watershed management 156–157
 adoption of technology 200, 201, 208–209, 212, 214
 farmer participation 201, 208–209
 microwatershed development 209–212
 model for 201–202
 monitoring and evaluation 212–213
 new science tools for evaluation and management 202–207
 on-farm trials 200–201
 on-station research 207–208, 209
- semi-dwarf trait 110
- senescence, delayed 136, 138
- sewage effluent, use of treated 180
- shading, agroforestry 222
- shared water 182
- short-duration crops 110–111, 132–133, 140
- shrimp farming 279
- SIDA *see* Swedish International Development and Cooperation Agency
- slopes, agroforestry 220–221, 225
- socio-economic factors 24, 158–159, 182
- soil
 alternate wetting and drying (AWD) 59, 60, 63
 salinity/alkalinity 3, 72, 74–75, 91, 260–261
 saturated culture (SSC) 59, 60–61
- soil aeration 59, 60, 63
- soil conservation 155
- soil evaporation 150, 151, 220
- soil fertility
 boron and sulphur amendments 211–212
 dry areas 190–191
 semi-arid tropics 152–154, 153–154, 158
 wheat production 262, 263
- soil infiltration 91, 220
- soil leaching 75, 92, 94–96, 97–98
- soil moisture, agroforestry 220–221
- soil nutrients
 boron 211–212
 sulphur 211–212
 uptake by roots 223–224, 315–317
 watershed management 211–212, 213
- soil puddling 59, 247–248, 250
- soil redox potential 63
- soil–water balance 290
 simulation modelling 202–205
- Solanum tuberosum* *see* potato
- sorghum
 agroclimate 128–129
 drought tolerance 136–138, 140
 pigeonpea intercropping 208, 209, 210
 short-duration genotypes 132–133
 stay-green genotypes 111, 136, 138
 supplemental irrigation 153–154, 208, 209
- sorghum–wheat cropping 77
- South Africa, savannah 224
- sowing
 direct 60, 63, 106–107, 320
 surface 242
 timing 189, 192, 243–244, 320
- soybean
 pigeonpea intercrop 208
 soil boron and sulphur treatments 211
 yield simulations 205–206
- SRI *see* System of Rice Intensification
- Sri Lanka, Gal Oya Water Management Project 27–28
- SSC *see* saturated soil culture
- stay-green trait 111, 136, 138
- steppe 186–187
- stomatal function 105, 108–109, 312–313
- storage tanks, subsurface 155
- straw mulch 242, 243
- sub-Saharan Africa
 cereal water productivity 1995 167–168
 cereal water productivity 1995–2025 170–172
 dependence on rain-fed agriculture 146
 rainfall partitioning 150, 151
 supplemental irrigation 152–154
- suberin 109
- submergence tolerance 111–112
- subsoilers 156
- SUBSTOR-Potato model 236–237
- sucrose synthase 110
- sugar cane 295
- sulphur 211–212
- supplemental irrigation 152–154, 181, 185–186
 deficit 188–189, 194–195, 305–308

- microirrigation 155
- semi-arid tropics 208, 209
- socio-economic factors 158–159
- and soil fertility 158
- wheat production 192–193
- surface energy-balance algorithm for land (SEBAL) 291–292
- surface runoff *see* runoff
- surface seeding 242
- sustainability 25, 28–29, 64, 218–219
- Swedish International Development and Cooperation Agency (SIDA) 145*n*
- Syria
 - deficit irrigation 194–195, 305–308
 - legume production 188, 189, 192
 - soil management 190–191
 - water harvesting 187
 - wheat production 185–186, 188, 192–193, 194–195, 302–308
- System of Rice Intensification (SRI) 26, 27
- tank irrigation systems 205, 206–207
- Tanzania 149
- technology adoption 26, 27
 - constraints 26, 201
 - farmer incentives 12–13
 - Indo-Gangetic plains 249, 250–251
 - integrated watershed management 200, 201, 208–209, 212, 214
 - rice production 26, 27, 62–64
 - social benefits 24
- terracing 155
- Thailand
 - Chao Phraya basin 29, 64, 276–277, 279–280, 283, 285
 - crop choice 279–280
 - Energy General Authority 276
 - Mae Klong basin 277, 285
 - types of river basin 285
 - water allocation 280–283
 - water laws 274, 283–284
 - water pricing 277–278, 285
 - water scarcity 274
 - water-use efficiency 275–277
- Thompson, Sir G. 37
- tillage
 - reduced (conservation) 155–156, 244–245, 319–320
 - rice production 59, 63
 - zero 155–156, 242–244, 249, 320
- timber production 226
- tomato 208, 209
- total factor productivity (TFP) 22
- trade, cereals 29, 30, 177
- transfer of water
 - large scale 180
 - non-agricultural uses 24
 - saline conditions 82–84, 99, 100
 - see also* reallocation of water
- transpiration 103–104
 - agroforestry system 221
 - beneficial functions 313–315
 - and drought 131
 - physiological process 105–106, 312–313
 - plant traits minimizing 108–109
 - role in nutrient uptake 315–317
- transpiration:photosynthesis ratio 109
- trees
 - ecological functions 218–219, 226
 - hedgerow 220–221, 224, 225
 - interactions with crops 223–225
 - potential benefits in crop systems 217, 219–221
 - transpiration pull 313–314
- Tropicultor, bullock-drawn 209, 210
- tube wells 32–33, 85, 86, 276
- Turkey 12–13, 28–29, 180
- under-irrigation *see* deficit irrigation
- USA
 - cereal productivity 1995 168, 169
 - reallocation of water 283
 - water law and management 48, 281
 - wheat production 302–305, 307
- van der Heide, H. 273–274
- varietal improvement 25–26
 - see also* molecular biology; plant breeding
- Vertic Inceptisols 208
- Vertisols
 - ICRISAT technology package 200, 201, 207
 - productivity potential 207–208, 209
- Vitellaria paradoxa* 222
- WANA *see* West Asia and North Africa
- WARDA *see* West Africa Rice Development Association
- WATBAL model 202–204
- water accounting 3–6, 23
 - basin scale 4, 5–6
 - definitions 4
 - field scale 3, 4
 - irrigation systems 3–5
- water depletion 3–5
 - beneficial 3–5, 44–45
 - defined 3*n*, 4
- ‘water efficiency paradox’ 37–38
- water harvesting
 - downstream impacts 147, 157
 - dry areas 186–187
 - microirrigation 155
 - semi-arid tropics 52–53, 205, 206–207
 - socio-economic factors 158–159
- water laws 281
 - implementation 284
 - Thailand 274, 283–284
- water losses, irrigation 39
- water markets 48–49
 - small-scale 82–84
- water multiplier effect 46
- water pricing 31–32, 48–49, 180–181
 - China 31–32
 - Thailand 277–278, 285
- water productivity (WP)
 - concept and definitions 22–23, 182–183
 - economic 22–24, 46–47
 - partial factor productivity (PFP) 22–23
 - per kg water input
 - rice 57
 - wheat 57
 - per unit available water 7–8
 - per unit depletion 57, 104, 105, 294–295
 - per unit diverted 6, 7, 57, 104, 105, 294–296
 - per unit rainfall 152

- water productivity (WP) *continued*
 physical 22, 46–47
 scale of analysis 2–3, 8–9, 17, 23, 57, 58, 297–298
- water quality 33, 180
- wheat production 261, 263, 266
see also alkalinity; salinity
- water resource degradation 24–25, 33
- water savings 13–14, 64
- water scarcity 1–2, 37, 301
 dry areas 181–182
 economic 2, 54
 management-induced 2
 physical 54
 projections 147–148
 rice-growing areas 54
 semi-arid tropics 200
 socio-economic impacts 182
 Thailand 274
- water stress
 complexity 127–128
 and flowering 115, 316
 indicators 189
 and plant growth cycle 114–115, 306, 308
 rice 115–116
 sensitivity index 306, 308
 and yield 115–116, 189
- water table, shallow saline 78, 92–93
see also groundwater
- water taxes 274*n*
- water valuation 23, 46–47
- water wholesaling 277–278, 285
- water withdrawals
 blue water 147–149
 global estimated 1995 166, 174
 global projections 147–149, 166, 174
 green water 148–149
 impacts of future global reductions 174–177
- water-use efficiency
 scale of analysis 275–276, 297–298
 semi-arid tropics 152
 Thailand 275–277
- waterlogging tolerance 111–112
- watershed
 functions of trees 218–219, 225–226
 water budget simulation 202–205
- watershed management 156–157
 adoption of new technology 200, 201, 208–209, 212, 214
 farmer participation 201, 208–209
 microwatershed development 209–212
 model for 201–202
 monitoring and evaluation 212–213
 new science tools for evaluation and management 202–207
 on-farm trials 200–201
 on-station research 207–208, 209
- weed management
 rice 63, 64, 107
 wheat 245–246
 zero tillage 243, 244
- wells 32–33, 85, 86, 276
- West Africa, agroforestry 224
- West Africa Rice Development Association (WARDA) 107
- West Asia and North Africa (WANA)
 additional water sources 180
 crop germplasm improvement 192–193
 cropping systems 190
 effective water management 180–181
 future directions and research issues 195–197
 integrated approach to water management 183–184
 simulated cereal water productivity 1995–2025 170–171
 soil management 190–191
 water scarcity 179, 181–182
 water-use efficient techniques 185–189, 193–195
- Western Australia 16
- wheat
 crop–water production functions 302–304
 lodging 246
 salinity tolerance 79, 90, 91
 water stress 186, 306, 308
 weed management 243, 244, 245–246
- wheat production
 bed-planting 245–247
 dry areas 185–186
 fertilizer use 262, 263
 global 230
 India and Pakistan 256
 Indus basin 294, 295–298
 research literature 256–257
 saline/alkaline conditions 75–77, 78, 82
 seeds 263
 supplemental irrigation 155, 188, 192–193, 304–308
 surface seeding 242
 water productivity 57, 193–195
 water quality 261, 263, 266
 yields 256
 factors affecting 260–264
 and irrigation water management 261–263, 267–268, 269, 270
 variability 258–260, 268
 yield function analysis 264–266
see also rice–wheat cropping
- women 212
- World Bank 31
- Yellow River, China 32, 55
- yield-function analysis 264–266
- yield-gap analysis 205–206
- youth 212
- zero tillage 155–156, 242–244, 249, 320
- Zhanghe irrigation system, China 31–32, 55
- Zimbabwe 305, 307