GEOL 408/508

SOIL QUALITY
AS AFFECTED BY
HUMAN ACTIVITIES

Chapter 20

Brady and Weil, Rev. 14th Ed.

THE CONCEPT OF SOIL QUALITY/SOIL HEALTH

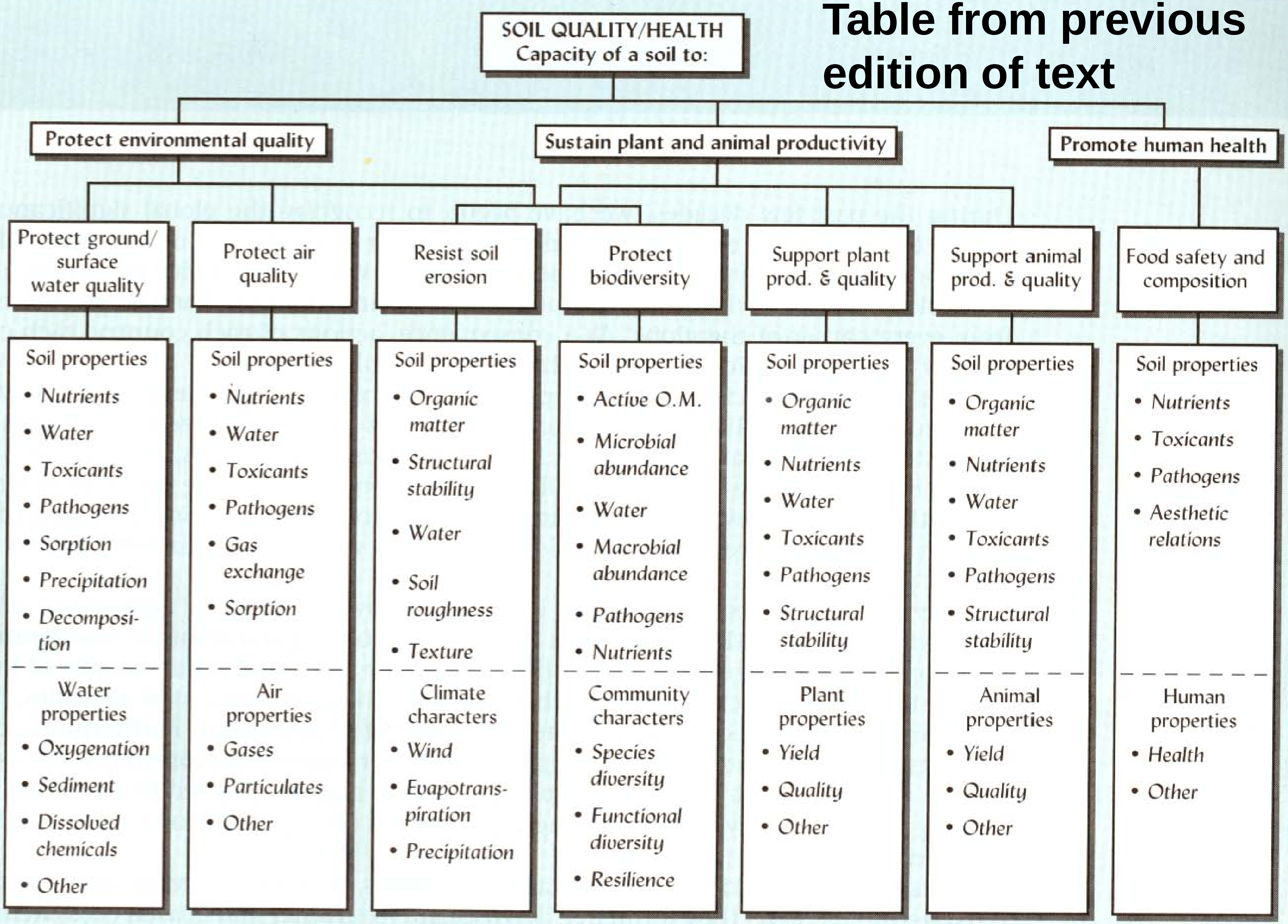
Soil health is best used to refer to condition of soil as a result of management.

Soil quality is the capacity of a soil to function within its ecosystem boundaries to sustain biological **productivity** & **diversity**, maintain **environmental quality** and promote plant & animal **health**. [see Figure 20.1]

Assessing soil quality:

- **indicators** are soil properties that are measured to estimate rates/function of physical, chemical or biological processes [Table 20.1]
- **soil-quality index** is determined by weighing indicator in accordance with its presumed importance
- computed for each soil ecosystem

Table from previous edition of text



SELECTED INDICATOR PROPERTIES FOR DETERMINING THE QUALITY OF SOIL HEALTH

TABLE 20.1 Selected Biological, Chemical and Physical Indicator Properties for Determining the Quality of Health of a Soil

The soil ecological functions are further explained in Figure 20.1 and some of the listed indicator properties are evaluated in terms of soil quality score in Figure 20.2.

Most Closely Associated Soil Ecological Functions								
Nutrient cycling	*Water relations*	*Stability-support*	*Buffering-filtering*	*Resilience-resistance*	*Biodiversity habitat*	*Property symbol*	*Property Description*	*Related book sections*
						Biological Properties		
X				X	X	MI	Maturity index of nematode trophic levels	Sections 11.2, 11.6
				X	X	qCO_2	Respiration (per unit microbial biomass per day)	Section 20.8
			X		X	MBC	Microbial biomass carbon	Sections 12.2, 20.8
X						MBP	Microbial biomass phosphorus	Sections 14.4, 20.8
X			X			PMN	Potentially mineralizable nitrogen	Section 13.3
X	X			X	X	Active C	Organic carbon oxidized by 0.02 *M* $KMnO_4$	Sections 12.2, 12.6
						Chemical Properties		
X			X		X	Soil test P	Available phosphorus by soil test (e.g. Mehlich 3)	Section 16.11
X			X	X		P_{sat}	Saturation of P fixing capacity ((Al+Fe)/P)	Section 16.12
X			X		X	Soil test K	Available potassium by soil test (e.g. Mehlich 3)	Section 16.11
X			X	X	X	Soil pH	Soil pH (in 1:1 water solution)	Section 9.5
	X	X		X	X	EC	Electrical conductivity	Section 10.4
X	X	X	X	X	X	SAR	Sodium absorption ration	Section 10.4
X	X	X	X	X	X	TOC	Total organic carbon	Section 12.6
X			X	X		CEC	Cation exchange capacity	Section 8.9
						Physical Properties		
X	X	X	X	X	X	AGG	Aggregate stability to slaking when wetted	Section 4.5
X	X	X		X	X	D_b	Bulk density	Section 4.7
X	X	X	X	X	X	Depth	Depth to root limiting layer	Sections 5.9, 17.2
	X		X	X	X	AWC	Plant-available water-holding capacity	Sections 5.4, 5.8
	X	X	X	X		*S*	Infiltration capacity (sorptivity)	Section 5.6
	X	X		X	X	Sand	Percentage of sand in the mineral fraction	Section 4.3
X	X	X	X	X	X	Clay+Silt	Percentage of clay + silt	Section 4.3

Based on concepts in Andrews et al. (2004); Eigenberg et al. (2006); Karlen et al. (2006); Weil et al. (2003). For many of the methods, see Doran and Jones (1996).

THE CONCEPT OF SOIL QUALITY/SOIL HEALTH - 2

TABLE 20.2 Simplified Example of How Indicator Properties Can Be Combined to Give Soil Quality Indices[a]

For simplicity, only two examples of indicator properties are given for each ecological function. Note that an indicator (AGG in this example) may be used for more than one function. In the SQI all indicators and functions are given equal weight. In the SQI_w nutrient cycling is weighted to be 2 times as important as the other functions.

Management Goal	*Supporting ecological function*	*Indicator property*	*Measured value*	*Indicator score (S)*	*Weighting factor (w)*	*Weighted indicator score ($S \cdot w = S_w$)*
Plant production	Nutrient cycling	Soil test P	80 mg P kg soil^{-1}	10	2	20
		PMN	20 mg N kg soil^{-1}	8	2	16
		etc.	. . .	. . .	. . .	. . .
	Water relations	AGG	30%	8	1	8
		AWC	20 g H_2O g soil^{-1}	8	1	8
		etc.	. . .	. . .	. . .	. . .
	Physical stability	AGG	30%	8	1	8
		Db	1.4 Mg m^{-3}	6	1	6
		etc.	. . .	. . .	. . .	. . .
	Resilience	TOC	25 g C kg soil^{-1}	4	1	4
		SAR	1.0	9.5	1	9.5
		etc.	. . .	. . .	. . .	. . .
			Sum of scores or factors =	61.5	$n_w = 10$	79.5
				Average of S = 61.5/8 = 7.7 Unweighted Soil quality index (SQI) = 7.7 × 10 = 77		**Average of S_w = 79.5/10 = 8.0 Weighted Soil quality index (SQI_w) = 8.0 × 10 = 80**

[a] Indicator abbreviations are explained in Table 20.1. See Box text for equations to calculate SQI and SQI_w. See Figure 20.2 for typical curves used to convert measurements to indicator scores.

THE CONCEPT OF SOIL QUALITY/SOIL HEALTH - 2

Soil-quality index for erosivity: an example:

- from Table 20.1, four functions of soil resisting water erosion:
  - (1) accommodating water entry (50%)
  - (2) facilitating water transfer & adoption (35%)
  - (3) resisting degredation (10%)
  - (4) sustaining plant growth (5%)
- soil with sustainable farming practices = 0.84
- field with conventional, high intensity pract = 0.60

Time- and place-sensitive functions:

- importance and priorities change over time & vary from place to place at the same time
- environmental concerns becoming more impt in US
- food & fiber prod’n tops by far in develop’n areas

THE CONCEPT OF SOIL QUALITY/SOIL HEALTH - 3

Management-sensitive indicators (Fig 20.4):

- many soil properties that cannot be promptly altered by management
- others will respond almost immediately
- intermediate factors should be focus of long-term soil management

Ephemeral	Intermediate	Permanent
Changes within days or routinely managed	Subject to management over several years	Inherent to profile or site
• Water content	• Aggregation	• Soil depth
• Field soil respiration	• Microbial biomass	• Slope
• pH	• Basal respiration	• Climate
• Mineral N	• Specific respiration quotient	• Restrictive layers
• Available K	• Active C	• Texture
• Available P	• Organic matter content	• Stoniness
• Bulk density		• Mineralogy

(Fig 20.4)

SOIL RESISTANCE AND RESILIENCE

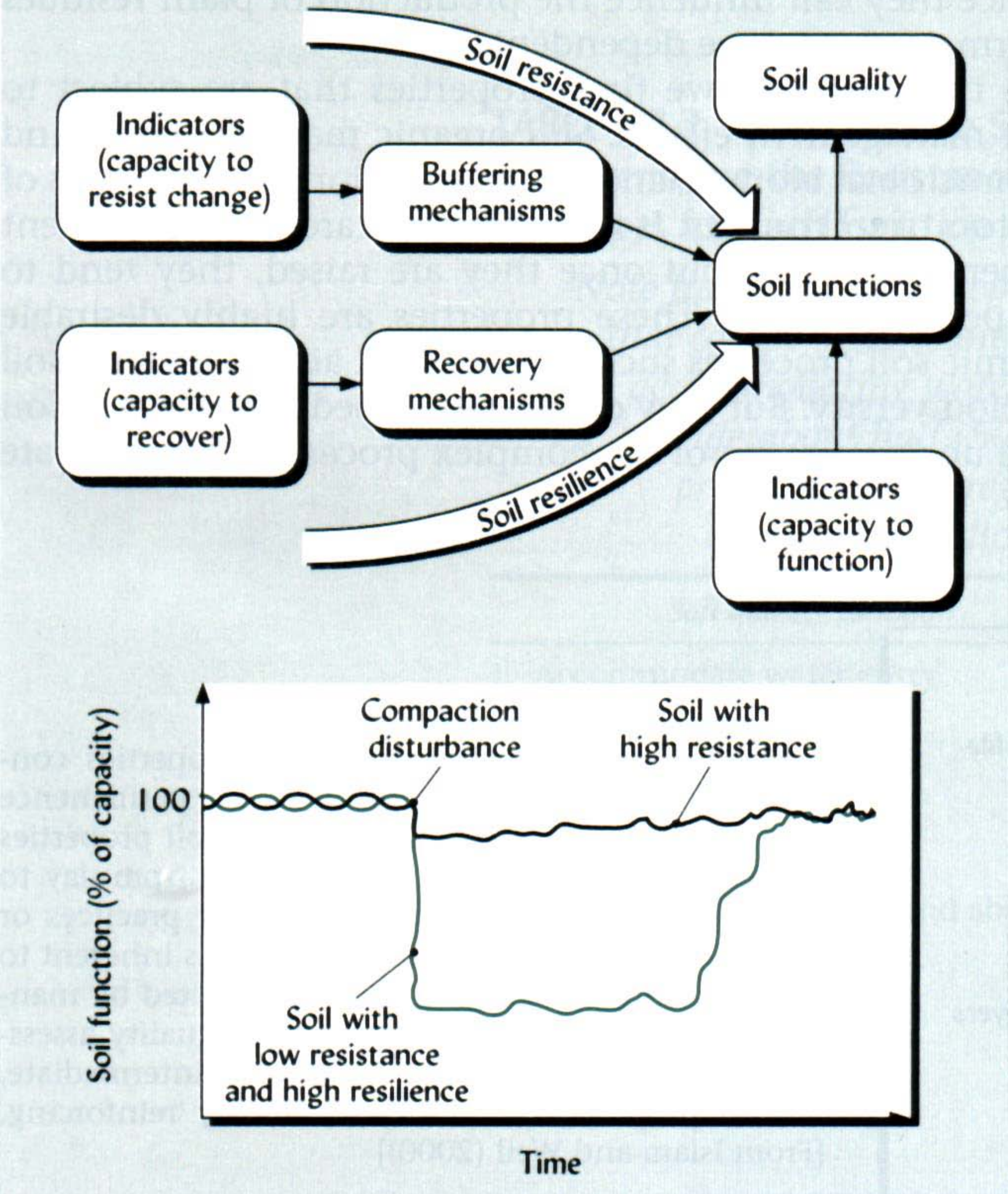
Soil resistance is the capacity of a soil to resist change when confronted with force or disturbance

Soil resilience is the capacity of a soil to rebound from changes stimulated by disturbances of external forces

Factors affecting soil resistance and resilience:

- inherited characteristics such as texture, type of clay minerals, slope, climate
- dynamic properties such as vegetation type, nutrient cycling, water & land management
- three primary functions must be performed if soil quality is to be considered satisfactory:
- biological productivity; maintaining environ quality; enhancing human & animal health

CONCEPT OF SOIL RESISTANCE AND RESILIENCE



Can you relate these concepts to your foot prints in wet soil?

(Fig 20.5)

SUSTAINING BIOLOGICAL PRODUCTIVITY

The first 10,000 years:

- agricultural activities had little overall effect on soil productivity - people could easily move
- Mesopotamia, Greeks & Romans severely affected local soil quality & productivity but could import food

Past half century:

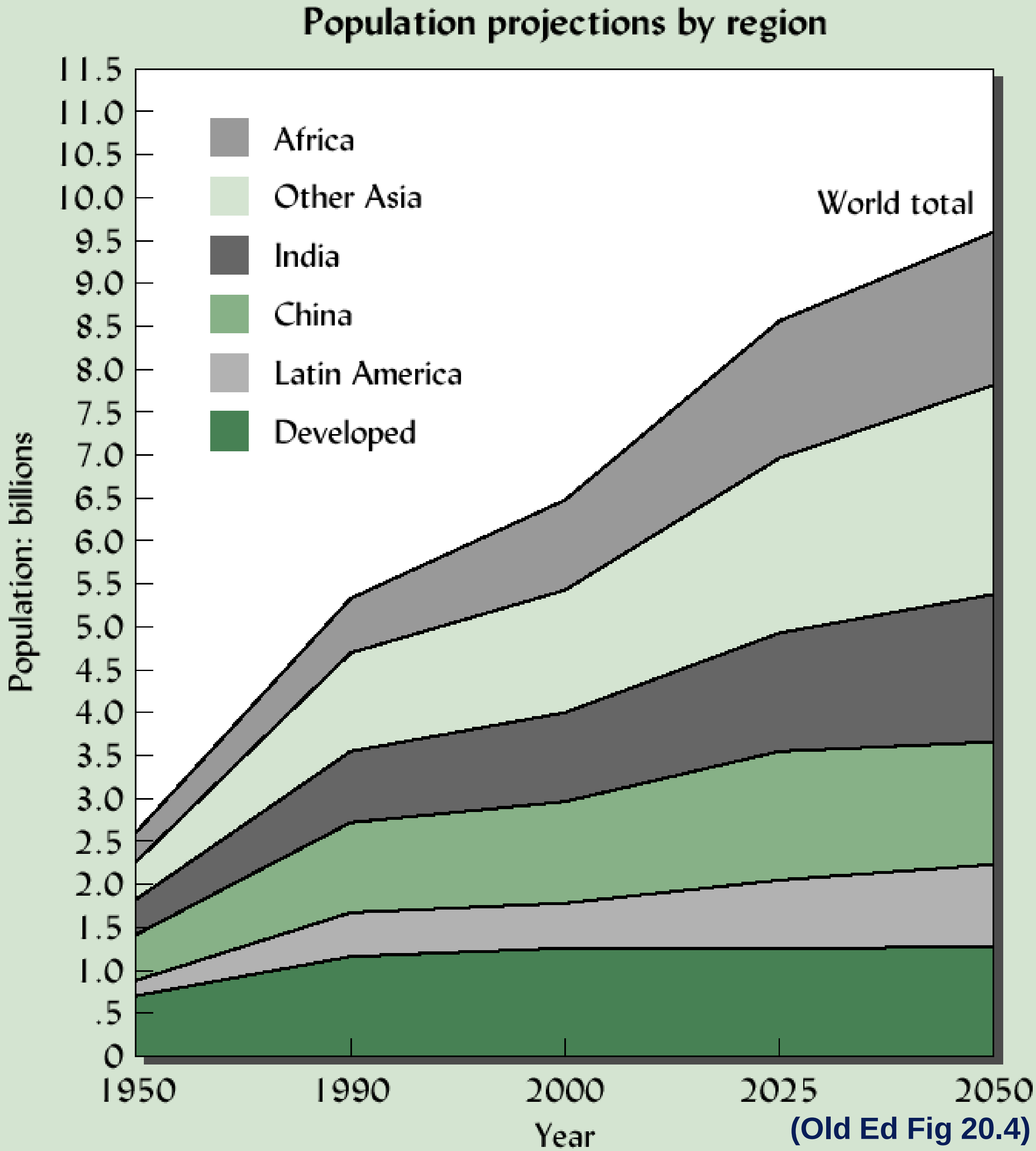
- extreme pressures on land for food & fiber production
- unprecedented increases in population
- enhanced ability to purchase food & fiber that others produce (consum beyond basic needs)

THE POPULATION EXPLOSION

To meet unparalleled demands for food:

- had to clear & cultivate native forests or water-deficient grasslands

- had to greatly increase cropping intensity & yields per hectare on more productive lands

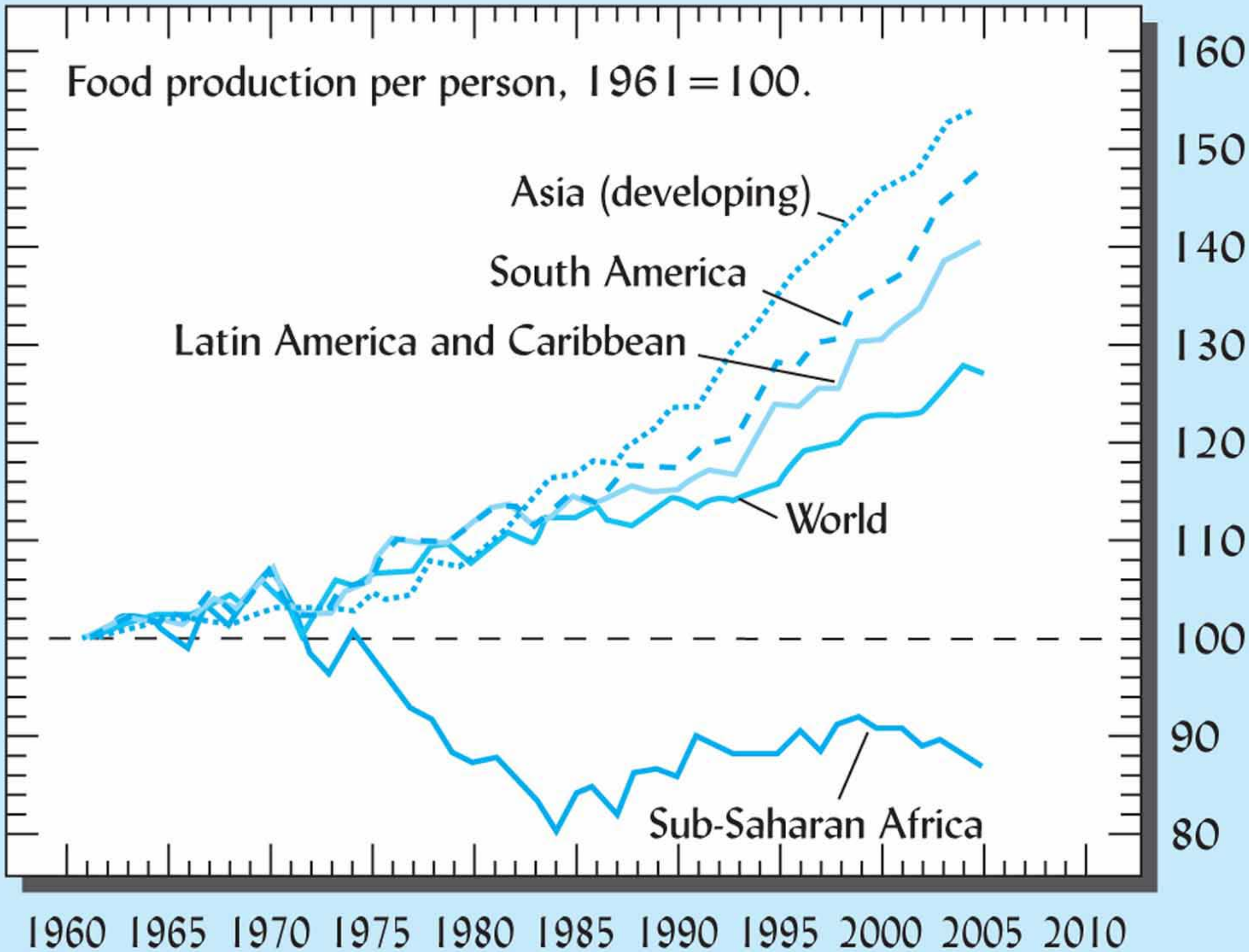


(Old Ed Fig 20.4)

INTENSIFIED AGROECOSYSTEMS - THE GREEN REVOLUTION

- Past experts seriously understated the ability to increase production on existing agricultural lands
- Food production has increased more rapidly than population in all regions except sub-Saharan Africa
- Reasons are improved crop varieties, use of irrigation & chemical fertilizers
- Grain harvests nearly tripled worldwide from 1959 to 1990
- More than 70% of increases came from intensified farming
- Worldwide production is more than sufficient; distribution is not

CHANGES IN PER CAPITA FOOD PRODUCTION



(Fig 20.9)

EFFECTS OF INTENSIFIED AGROECOSYSTEMS ON SOIL QUALITY OR HEALTH

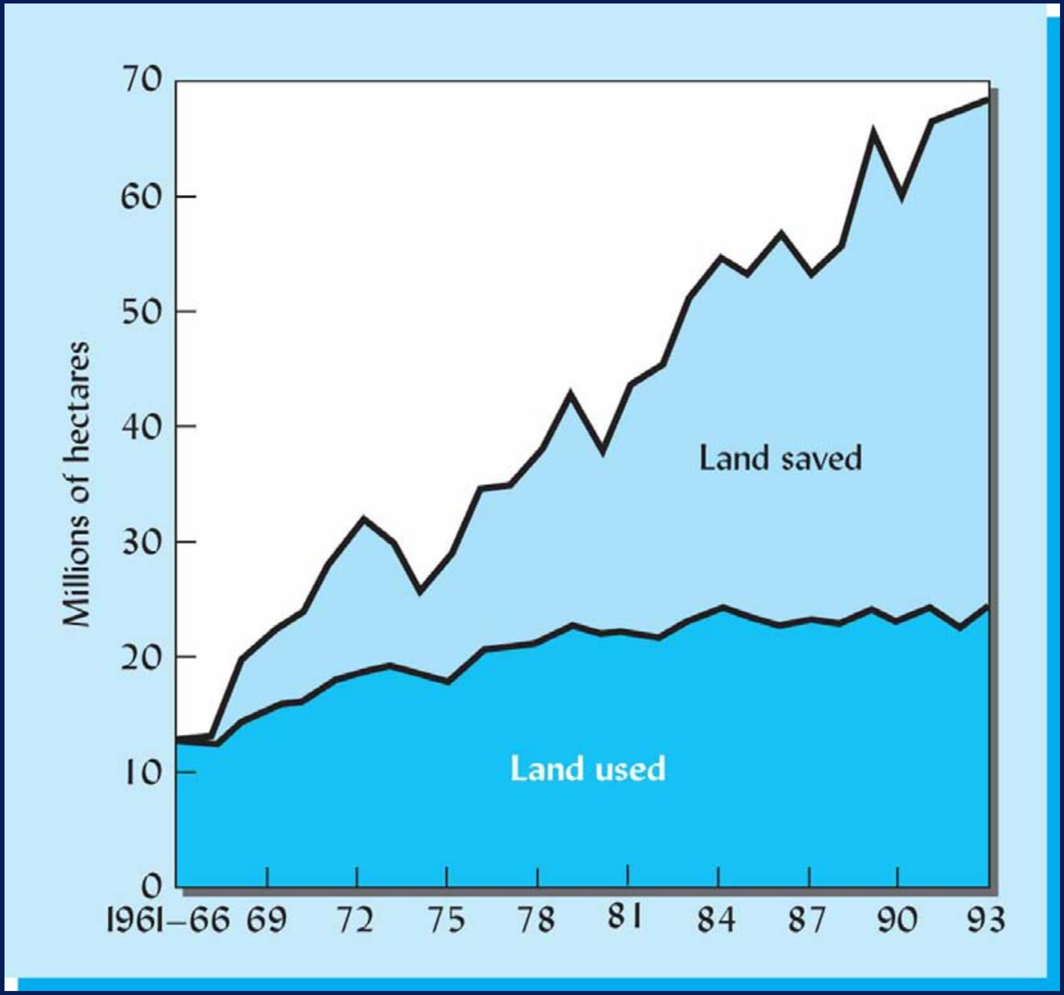
Positive effects:

- has generally maintained or increased levels of some macronutrients
- increased plant production with corresponding incr. in amt. of crop residues to return to soil
- tendency to reduce pressures on fragile lands that otherwise might have been used (Fig 20.12)
- increased efficiency of nutrient use due to improved crop varieties

LAND SAVED AND FOOD PRICE INDEX IN INDIA

Benefits of increased crop productivity

Land saved from use for cultivation in India by the adoption of improved techniques and crop varieties.



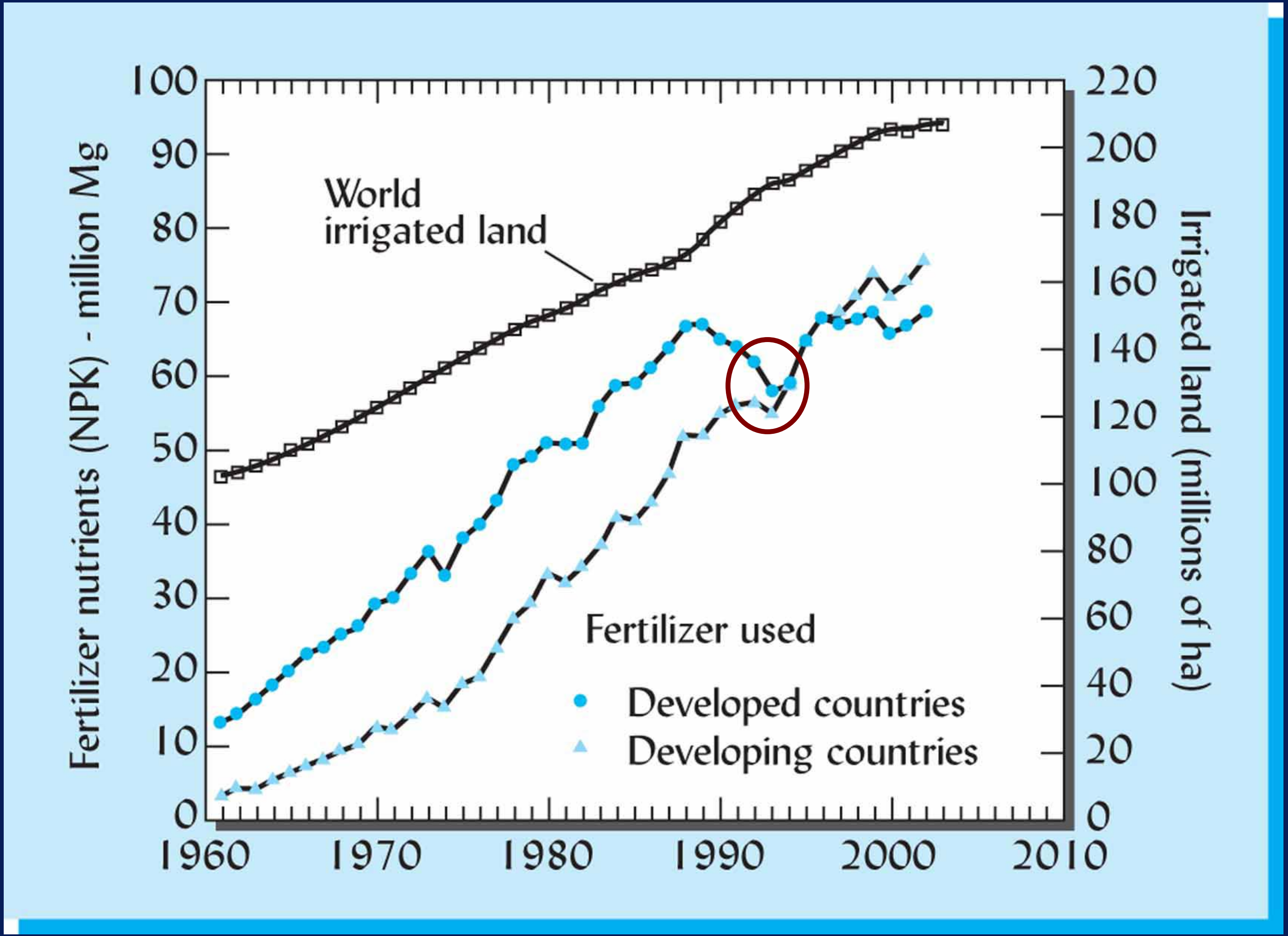
EFFECTS OF INTENSIFIED AGROECOSYSTEMS ON SOIL QUALITY OR HEALTH

Negative effects:

- micronutrient deficiencies due to heavy fertilization of macronutrients & high yields

- **Excess nutrients:**
  - overapplication of N & P in many world regions; are now water pollutants (Fig 20.9)
- **Salinization:**
  - due to irrigation; affected 30% of irrigated soils
- **Pesticides:**
  - build-up in soils; non target organisms affected
  - need to use integrated pest management

RATES OF FERTILIZER USE IN SELECTED WORLD REGIONS



EFFECTS OF INTENSIFIED AGROECOSYSTEMS ON SOIL QUALITY OR HEALTH

Negative effects:

- **Healthy diet:**
  - major focus has been on cereal crops (corn, rice, &)
  - less attention to pulses, fruits, vegetables
  - less micronutrients, vitamins, proteins in diets
- **Plant disease:**
  - cereals are grown in monocultures; noted declines in productivity may be due to increased pathogens or of allelochemicals
- **Reduced biodiversity:**
  - monocultures reduce diversity of soil organisms
  - same crop & residue type

FORCED PRODUCTION INTENSIFICATION

Many peoples have utilized indigenous pastoral & crop-production systems that depend upon natural vegetation to rejuvenate soil quality between periods of use

With increased population, time for soil rejuvenation has greatly increased and soil is overused

Shifting cultivation:

- **slash & burn small plots to cultivate for a few years; then move to new area & let old one recover**
- **continue process, returning to plots after 10-20 yrs**
- **most commonly used in tropics & subtropics**
- **with increased population pressure, fallow period has decreased & soil erosion & fertility decreased**
- **slash & burn contrib's 25%(?) of global warming**
- **see Figure 20.13**

CHANGES IN FERTILITY UNDER TWO SHIFTING-CULTIVATION SYSTEMS

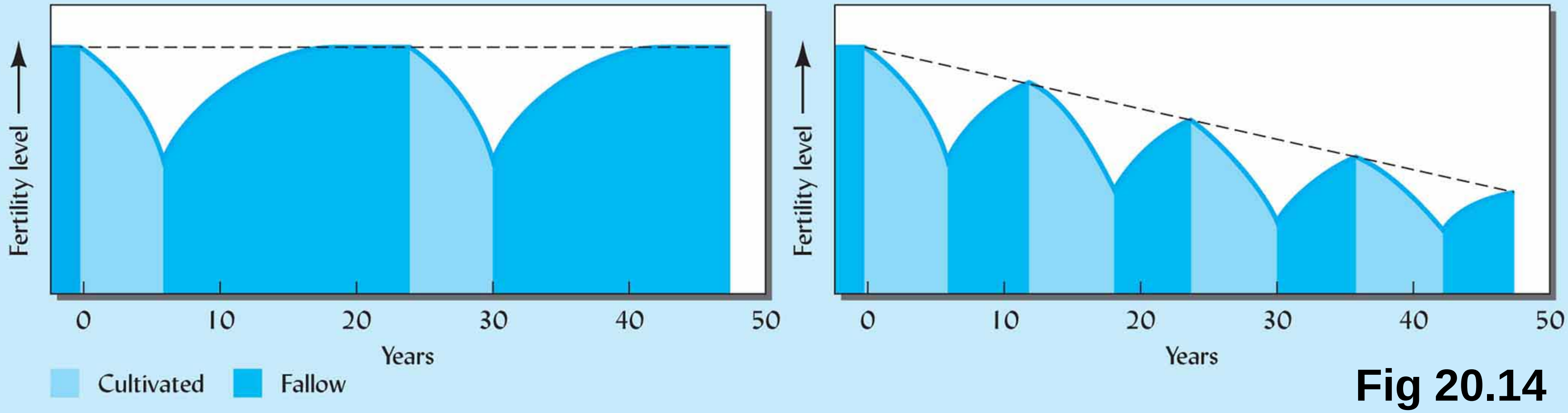


Fig 20.14

Soil fertility under two shifting-cultivation systems. The shorter than optimum fallow period results in declining soil fertility.

FORCED PRODUCTION INTENSIFICATION

Nomadic pastoral systems:

- on common lands in arid to semiarid areas
- increased animal numbers, less areas to graze
- decreasing soil quality, productivity; inc'd erosion

Marginal and urbanized lands:

- expansion into marginal (rolling to steep hillsides) lands has increased erosion with loss of fertility
- much soil degradation is irreversible
- urban sprawl has consumed large land areas, much of this was prime agricultural land
- during past half century, 2 billion ha of land have suffered degradation
- soil quality has declined on 38% agric land, 21% permanent pasture & 18% forests & woodlands

PROSPECTS FOR FUTURE

Demands for food and fiber:

- in next 25 years, 2.5 billion more people
- economic growth in most developing countries will also increase demand
- as incomes rise, demand for meat increases
- much more grain is required to feed people on animal products than if the grains were directly consumed
- by 2010 in developing countries, 25% of grain will be fed to animals
- more food will have to be produced in the next 40 years than has been produced since the beginning of agriculture
- these demands will tax soil's plant-production function & environ quality, human & animal health & biological diversity functions as well

PROSPECTS FOR FUTURE - 2

Expansion of land under cultivation:

- most production will come from intensive agriculture on most productive lands
- some will come from expansion of arable land base
- most of Asia & Africa have little expansion options
- greatest potential for expansion in South America
- many areas will expand into marginal soils

Demands for environmental quality:

- society has increasing demand for improved environmental quality
- need for reduced erosion, nutrient pollution
- need to prevent continued soil degradation

PROSPECTS FOR FUTURE - 3

Constraints on meeting future food and fiber demands:

- irrigation water & chemical fertilizers will no longer produce increased production as in past
- many world regions are at capacity for fertilizer use
- higher levels will give diminishing returns & increase environmental pollution

A new paradigm of plant production:

- must satisfy enormous demands for food & for human & animal health without damaging environ
- in past, technology & short-term economic feasibility have been driving forces
- must now give greater consideration to ecological basis for food-production systems
- focus on systems that minimize losses & stewardship of natural resources

MODIFIED INTENSIVE AGROECOSYSTEMS

To maintain or improve soil quality, practices must:

1) reduce pollution of soil, water & the atmosphere
2) increase efficiency of nutrient & water use
3) maintain/increase quantity & quality of OM
4) decrease soil erosion
5) increase biological diversity

Maintenance of soil cover:

- need to keep soil surface at least partially covered at all times
- reduces runoff & erosion, conserves moisture
- microbial decay of OM enhances aggregate stabil.
- conservation tillage systems are economical
- additions of OM (residues, manure, green manure) needed at proper rates

MODIFIED INTENSIVE AGROECOSYSTEMS - 2

Nutrient management:

- must be reductions in rates of application in USA, Europe & Asia where additions now exceed uptake
- areas such as sub-Saharan Africa must increase inputs of nutrients
- all regions need greater efficiency of nutrient use & more effective recycling of all nutrients

• **Organic/inorganic combinations:**

- can maintain or increase yields over inorganic only
- gives enhanced nutrient cycling & improves soil quality
- can use less inorganic fertilizer

MODIFIED INTENSIVE AGROECOSYSTEMS - 3

- Crop rotation:
  - improves yields of all crops in rotation
  - including legumes increases N in soil
  - increases active fraction of soil OM &
  - use of close-growing crops help control erosion
  - use of fall or winter cover crops control erosion & conserve nutrients/reduce pollution
  - growing interest in utilizing organic & natural rock sources of plant nutrients & nonchemical means of pest control
  - there are significant resources of rock dust from quarrying operations - these are "organic" farming methods - have lower input costs & higher prices for produce

MODIFIED INTENSIVE AGROECOSYSTEMS - 4

Water management:

- water scarcity likely to limit future food production
- need to increase efficiency of water ues
- crop rotations with close-growing crops, conserv. tillage will increase soil water & decrease runoff
- change types of irrigation systems (drip, etc)
- improve drainage systems to reduce salt buildup

Biological diversity:

- diversity of cops in rotation, esp including legumes, will increase biological diversity in soil
- greater number & diversity of microorganisms
- should enhance essential physical, chemical & biological processes relative to soil quality

IMPROVING LOW-YIELDING AGRICULTURAL SYSTEMS

- Improved management of low-yielding systems essential for well-being of hundreds of millions of poor people in developing countries
- Sub-Saharan Africa & some other areas have negative balance of nutrients
- Soil constraints are reasons for low productivity in many areas in tropics (Al toxicity, acidity, high P fixation, salinity)
- Need for improved nutrient cycling, erosion protection & nutrient inputs

IMPROVING SOIL QUALITY IN SUB-SAHARAN AFRICA

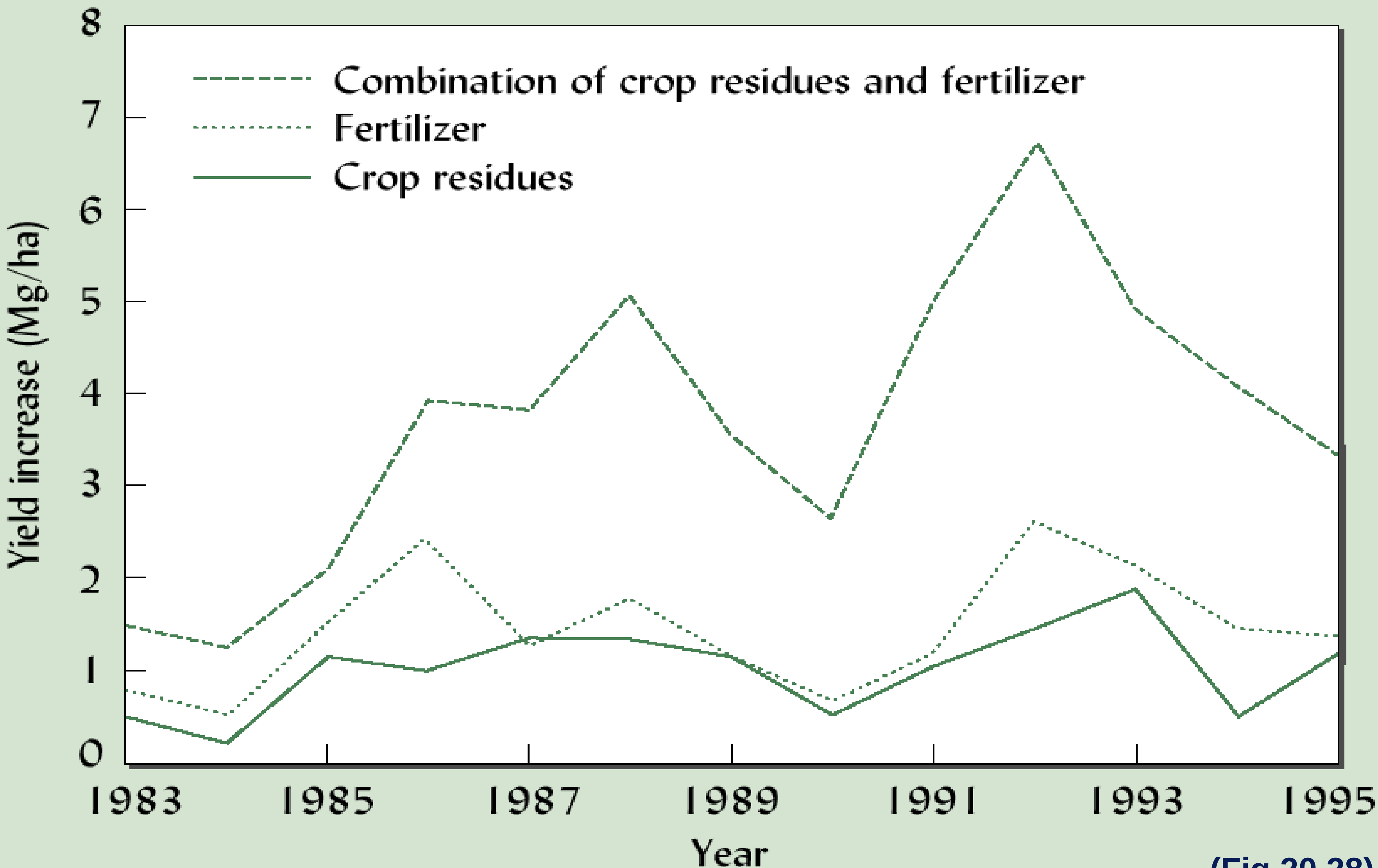
Nutrient deficiencies:

- negative balance of nutrients (Table 20.10)
- low yields but very low rates of fertilization
- few local sources of manufactured fertilizers
- transportation costs high - twice int'l price
- shifting agric in remote areas is also hindrance
- need innovative combinations of organic & inorganic nutrient sources

Nutrient management:

- use of fast-growing trees to recover leached N; add residues to soil
- use of N-fixing trees during fallow period; add residues to soil; also as co-crop
- use organic/inorganic combinations (Fig 20.26)

ORGANIC, INORGANIC AND COMBINATION FERTILIZATION



(Fig 20.28)

IMPROVING SOIL QUALITY IN SUB-SAHARAN AFRICA

Agroforestry systems as alternatives to slash-and-burn:

- **Mixed tree crops:**
  - domesticated tree crop planted among native trees
  - may have a number of cultivated crops (trees)
  - always will have vegetation on soil
  - produce high value crops (fruits, nuts, medicines)
- **Alley cropping:**
  - grow food crops in alleys between-fast growing trees or shrubs, usually legumes
  - trees are regularly pruned to prevent shading; prunings are added to soil
  - not always successful in very nutrient poor areas
  - need to design cropping system to fit situation

ALLEY CROPPING SYSTEM

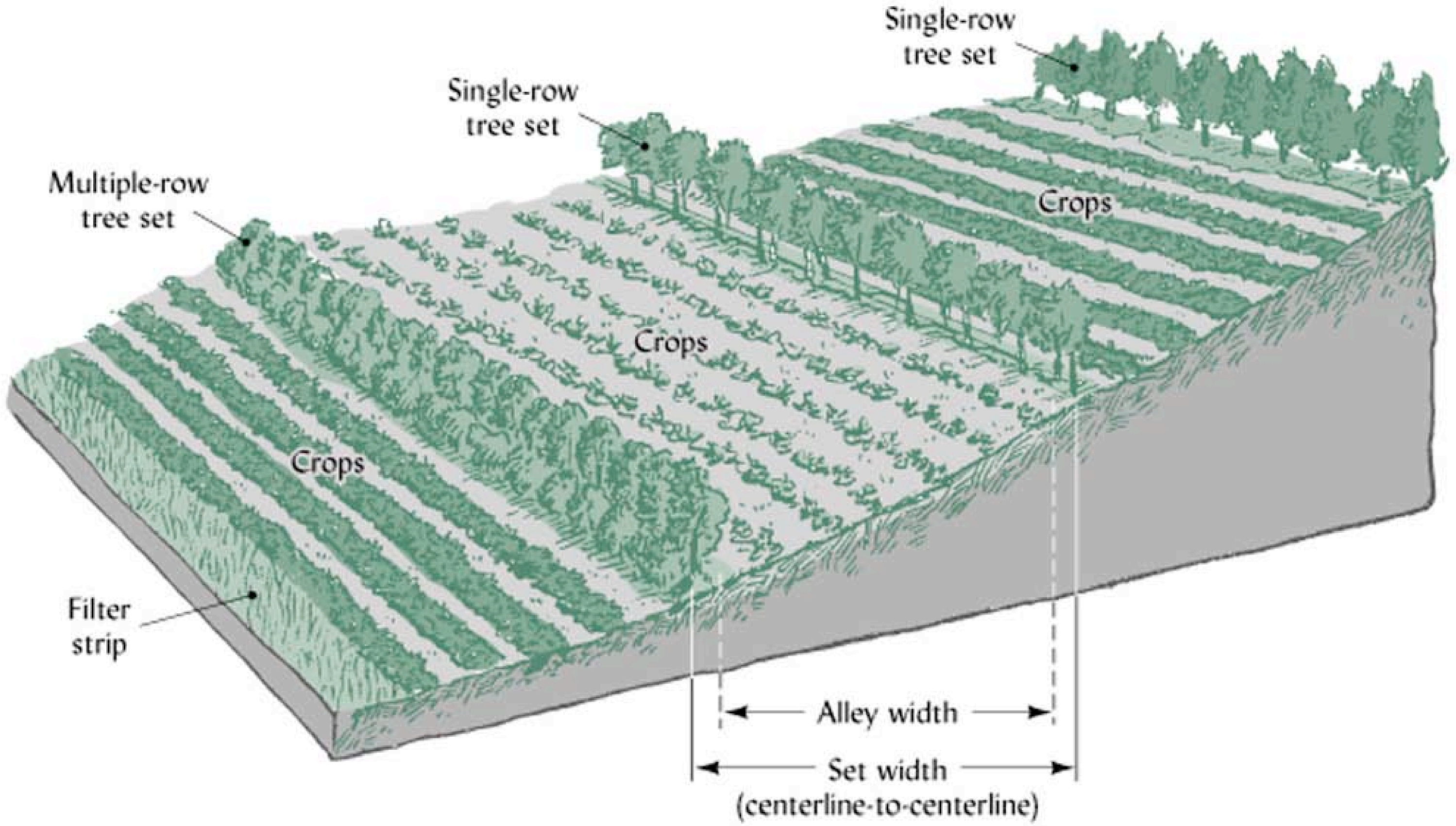


Fig. 20.26

IMPROVING SOIL QUALITY IN ASIA AND LATIN AMERICA

South and Southeast Asia:

- remarkable food-production increases have been due to increased use of fertilizers & water
- soil quality has been notably degraded due to intensive agric, burning or alt. use of crop residues
- severe soil erosion, decline in OM, soil structure

South and Central America:

- may have serious declines of soil quality in future
- care must be taken in areas that will be brought into production
- erosion rates in Central America are among highest in world
- need to expand agro/forestry systems and clear as little forest lands as possible

CONCLUSION

The concept of soil quality or soil health was developed to quantify factors that influence the ability of the soil to function in a variety of roles

The primary measures are enhanced biological productivity, environmental quality, human & animal health & biological diversity

Past food production increases have been the result of intensification of agriculture on existing lands

Major challenge is the production of more food & fiber in the next 50 years than in the last 10,000 years

A new paradigm is needed for an ecosystem approach for farming systems - an approach that emphasizes interaction of plant productivity with productivity & well-being of all organisms & environ quality