Food & Agriculture

Figures current as of October 2026

The crops, land, water, and fertilizer that feed eight billion people, the companies and traders, the policies and trade wars, hunger and nutrition, and the shocks of 2026.

MODULE 1 — Foundations: What Feeds the World

Goal: Establish the crops, the land, the calories, and who grows them.

The crops and calories in a table, land and yields by region, farm sizes, trade's share, and the water and energy inside food.

MODULE 2 — A Brief History: From Malthus to the Price Crises

Goal: Explain how the world escaped famine, what it cost, and how the system broke.

The timeline from domestication to 2026, Haber-Bosch, the Green Revolution, famine as politics, and the price crises of 2008, 2011, and 2022.

MODULE 3 — The Grains: Wheat, Maize, and Rice

Goal: Map the three staples with the numbers.

Production, exports, and imports by country for 2026/27, the price rise of 2026, and the balance after the record crops of 2025/26.

MODULE 4 — Oilseeds, Sugar, and the Soft Commodities

Goal: Cover the crops that compete for food, feed, and fuel.

Soybeans and the China pipeline, the vegetable oils and biodiesel, and sugar, coffee, cocoa, and cotton in tables.

MODULE 5 — Fertilizer: The Natural Gas Inside Food

Goal: Explain the input the whole system depends on.

Nitrogen, phosphate, and potash, the 2022 shock and Sri Lanka's ban, the 2026 Hormuz shock in a table, and the chain from gas to bread worked.

MODULE 6 — Seeds, Chemicals, and Machines

Goal: Profile the input industry and argue over how to regulate gene editing.

The seed and chemical companies, GM and gene-editing rules by country, glyphosate in court, Deere and precision farming, concentration, and the argument over gene editing.

MODULE 7 — The Traders and Processors

Goal: Follow grain from elevator to shelf and weigh the charge of 'greedflation'.

The ABCDs and their rivals, futures and basis with a hedge worked, packers, manufacturers, and retail, and the argument over profits in 2021-23.

MODULE 8 — Livestock, Meat, and Dairy

Goal: Cover the half of agriculture that eats the other half.

Feed conversion and footprints by product, the industry and the US cattle cycle, disease from swine fever to screwworm, and alternative proteins.

MODULE 9 — Fish and Aquaculture

Goal: Give the ocean and the fish farm their own module.

Wild catch and farming in the FAO's 2026 report, the species and the industry, fish oil and El Niño, and illegal fishing.

MODULE 10 — Land, Soil, and the Environment

Goal: Assess what farming does to the planet, with the Dutch nitrogen fight.

Deforestation by commodity and in 2025, emissions by source, soil and biodiversity, and the regulation fights from Brussels to the Netherlands.

MODULE 11 — Climate and the Harvest

Goal: Explain how warming is changing yields and what El Niño threatens.

Heat thresholds by crop, the 2026 season, the strong El Niño of 2026-27, water and pests, and adaptation.

MODULE 12 — Prices, Subsidies, and Stockpiles

Goal: Read the price record and the policy machinery, and argue over biofuel mandates.

The FAO index to September 2026, subsidies by country, American farm support, biofuels and stockpiles, the argument over mandates, and the politics of food inflation.

MODULE 13 — Trade Policy and Export Bans

Goal: Cover the rules and the weapons of food trade, with India's rice bans.

The WTO and the 2026 tariff ruling, the export-ban record in a table, India's rice bans, the US-China soybean war, and regulation as trade policy.

MODULE 14 — Hunger and Food Security

Goal: Confront who does not eat and why, with Sudan and Gaza.

The UN's 2026 hunger report by region, acute hunger and the famines in Sudan and Gaza, the aid collapse, and the paradox of waste.

MODULE 15 — Nutrition, Diets, and the Food Industry

Goal: Cover what people eat and who sells it, and argue over ultra-processed food.

The nutrition transition, ultra-processed food and the 2026 US guidelines, GLP-1 drugs, the argument over ultra-processed food, and the manufacturers.

MODULE 16 — The Geopolitics of Food

Goal: Examine food as weapon and vulnerability, with the Black Sea.

The Black Sea from 2022 to the port strikes of 2026, China's doctrine, the Gulf, India, Russia, and the United States, and the chokepoints.

MODULE 17 — Seven Food Systems

Goal: Profile the regions that feed and are fed.

The United States, Brazil, the EU, China, India, Sub-Saharan Africa, and the Middle East and North Africa in a comparative table.

MODULE 18 — The Technology Frontier

Goal: Separate what is changing farming from what was claimed.

Gene editing, stress-tolerant crops, precision farming and automation, biologicals, vertical farming, alternative proteins, and methane, with verdicts.

MODULE 19 — Where Things Stand, and What to Watch

Goal: Close with the trajectory, the lesson of the turning points, and a dated watch list.

Feeding ten billion, the lesson of the cases, the dependencies and demand shifts, the dates from October 2026 on, and a last word.

A note on the ground. Food statistics come from a few agencies that publish on their own schedules and revise often. Grain and oilseed figures here are the US Department of Agriculture's (USDA) World Agricultural Supply and Demand Estimates (WASDE) for the 2026/27 marketing year, and world prices are the UN Food and Agriculture Organization's (FAO) index and the World Bank's monthly averages, each named with its date. Long-run projections come from the Organisation for Economic Co-operation and Development (OECD) and the FAO. The table before Module 1 gives the source and release of each headline figure. Where the field argues, over gene editing, 'greedflation', biofuel mandates, and ultra-processed food, each side's case is put as its advocates make it, followed by the evidence and the course's reading. Figures are dated to October 2026.

Key Numbers, as of October 2026

The harvests, prices, and records the course relies on

Measure	Figure	Period	Source and release
World grain and oilseed crops	Wheat 822 million tonnes (Mt), below 2025/26's record 844 Mt; maize about 1,295 Mt; milled rice 534 Mt; soybeans a record of about 443 Mt	2026/27 projections	USDA, WASDE (September 2026, with the October 9, 2026 revisions)
World stocks	Wheat 276 Mt, maize 280 Mt, soybeans 124 Mt at the end of the season; China holds about 44% of the wheat and three-fifths of the maize	End of 2026/27	USDA, WASDE (October 9, 2026)
US harvest	Maize 16.0 billion bushels (407 Mt) at 181.2 bushels an acre; soybeans a record 4.56 billion bushels; wheat 1.53 billion bushels, down more than a fifth	2026	USDA, WASDE (October 9, 2026)
World food prices	FAO Food Price Index 136.0 (2014-16 = 100), up 5.8% in a year and the highest since November 2022; all-time high 160.2 in March 2022; 2025 average 127.2	September 2026	FAO (October 2, 2026)
Commodity prices	US hard red winter wheat $347 a tonne; maize $240; Thai 5% rice $482; soybeans $524; palm oil $1,180; arabica coffee $7.26 a kilogram; cocoa $5.92 a kilogram	September 2026 averages	World Bank, Pink Sheet (October 2026)
Fertilizer	Urea (Middle East) $407.5 a tonne, after a second-quarter average of $693.5; American retail urea $683 per short ton, up 12% in a year	September and early October 2026	World Bank, Pink Sheet; DTN, the farm-data company (week to October 2, 2026)
Energy	Brent crude $104.28 a barrel (futures, October 8, 2026); natural gas about $3 per million British thermal units (MMBtu) in the US and about $26 in Europe	Early October 2026	Futures settlements; US Energy Information Administration
Hunger	645 million undernourished (7.8%); 266 million in acute food insecurity in 47 countries; famine confirmed in Gaza and Sudan	2025	*The State of Food Security and Nutrition in the World 2026* (SOFI), July 21, 2026; *Global Report on Food Crises 2026* (April 24, 2026)
Acute hunger hotspots	Sudan 19.5 million (41%) in crisis or worse, with famine confirmed in El Fasher and Kadugli; Gaza 1.4 million (67%) projected through December 2026, its famine declared over in December 2025	2026	Integrated Food Security Phase Classification (IPC), June and July 2026
Fish	235 Mt from fisheries and aquaculture; aquatic animals 195 Mt, 53% of them farmed	2024	FAO, *The State of World Fisheries and Aquaculture 2026* (June 2026)
Emissions	Agrifood systems 16.5 billion tonnes of CO2-equivalent, 32% of the human total; 8.1 billion on the farm itself	2023	FAO (October 29, 2025)
Forests	Tropical primary forest loss 4.3 million hectares (10.6 million acres), down 36%; Brazilian Amazon clearing 5,796 square kilometers (2,238 square miles), down 11%	2025; August 2024-July 2025	World Resources Institute (WRI), Global Forest Watch (April 29, 2026); Brazil's space research institute (INPE) (November 2025)
US farm economy	Net farm income $158.4 billion, down 2.6%; direct government payments $47.4 billion, up nearly 70%	2026 forecast	USDA Economic Research Service (September 3, 2026)
US food prices	Food up 2.7% in a year; food at home up 2.2%; eggs down 23%; beef and veal up 5.9%	August 2026	US Bureau of Labor Statistics (September 11, 2026)

Measure	Figure	Period	Source and release
Climate	El Niño advisory: a strong-to-very-strong event likely through January-March 2027; India's monsoon 12.6% below its long-term average	October 8, 2026; June-September 2026	US National Oceanic and Atmospheric Administration (NOAA), Climate Prediction Center; India Meteorological Department, via Reuters (September 30, 2026)
Diet	11% of US adults taking a glucagon-like peptide-1 (GLP-1) drug to lose weight; ultra-processed foods 55% of US calories	2026; 2021-23	Gallup (July 7, 2026); US Centers for Disease Control and Prevention (CDC) (August 2025)

A tonne is 1,000 kilograms, 1.10 US short tons, or 2,205 pounds. A bushel is 27.2 kilograms (60 pounds) of wheat or soybeans and 25.4 kilograms (56 pounds) of maize. A hectare is 2.47 acres. Prices are in US dollars; the euro averaged $1.15 in September 2026 (Federal Reserve).

Module 1 — Foundations

What Feeds the World

Recommended Reading / Reference

Book: Vaclav Smil, *How the World Really Works* (2022), the chapters on food and fertilizer

Reference: FAO, *Statistical Yearbook*; FAOSTAT, the FAO's online database; USDA, WASDE (monthly); Our World in Data, agriculture pages

1a. The Crops and the Calories

Food	World output	Main uses	Leading producers
Maize	About 1,295 Mt (2026/27)	Mostly animal feed; also ethanol, sweeteners, starch, and food in Mexico and Africa	United States, China, Brazil
Wheat	822 Mt (2026/27)	Mostly bread and noodles; about a fifth is fed to animals	China, European Union, India, Russia
Rice (milled)	534 Mt (2026/27)	Almost all eaten by people	India, China
Soybeans	About 443 Mt (2026/27)	Crushed into meal for feed and oil for food and fuel	Brazil, United States, Argentina
Vegetable oils	243 Mt (2026/27)	Cooking, processed food, biodiesel	Indonesia, Malaysia, China, Brazil
Sugar	About 180-190 Mt	Food; Brazil turns about half its cane into ethanol	Brazil, India
Roots and tubers	Nearly 900 Mt (2023)	Potatoes, cassava, sweet potatoes, yams: staples in Africa and the Andes	China, Nigeria, India, Democratic Republic of Congo
Vegetables and fruit	About 2.1 billion t (2023)	Nutrition more than calories	China, India
Meat	About 370-380 Mt (2025)	Fed largely on the grain and soybeans above	China, United States, Brazil, European Union
Milk	About 950 billion liters (2025)	Dairy, mostly consumed where it is produced	India, European Union, United States
Fish and other aquatic animals	195 Mt (2024)	Food and fishmeal; aquaculture now 53%	China, Indonesia, India, Vietnam

Sources: USDA (September and October 2026 reports) for grains and oilseeds; the International Sugar Organization and USDA for sugar; FAOSTAT for roots, vegetables, and fruit; OECD-FAO *Agricultural Outlook 2026-2035* for meat and milk; FAO, *The State of World Fisheries and Aquaculture 2026*. Mt is million tonnes; a tonne is 1.10 US short tons.

Humanity eats a narrow diet: rice and wheat each supply about a fifth of the calories people eat, and maize, the largest grain crop by weight, supplies about 5% directly and far more as meat, milk, and eggs. Cereals together supply close to half of all calories, and animal foods supply about a sixth of calories and two-fifths of protein.

The world grows about 2.9 billion tonnes of grain a year, but less than half of it is eaten by people, since about a third feeds animals and a growing share becomes fuel. Even so, the food supply comes to roughly 3,000 kilocalories per person per day, more than everyone alive needs, if it were shared out and not wasted.

1b. The Land and the Yields

Region	Cereal yield (t/ha)	Irrigated share of cropland	Note
United States	About 8	About a seventh	Maize 11.4 t/ha (181 bushels an acre) in 2026
European Union	About 5.5-6	Under a tenth	French wheat about 7
China	About 6.3	About half	Yields multiplied on fertilizer and irrigation
India	About 3.3	About half	Punjab's wheat above 5, on falling groundwater
Brazil	About 5	About a tenth	Two crops a year on the Cerrado
Russia	About 3	Small	Black-earth steppe; the largest wheat exporter
Sub-Saharan Africa	About 1.5	About 5%	The largest yield gap
World	About 4.1, against 1.4 in 1961	About a fifth, producing about 40% of food	Yields roughly tripled on similar area

Recent averages from the World Bank's World Development Indicators and FAOSTAT; irrigated shares are rounded. A tonne per hectare is about 15 bushels of wheat or 16 of maize per acre; a hectare is 2.47 acres.

About 37% of the earth's land is used for farming, with cropland covering about 1.6 billion hectares (4 billion acres), roughly 12% of the land, and pasture about twice as much. Almost all the good land is already in use, so expansion now comes at the expense of forests in the Amazon, the Cerrado, the Congo basin, and Southeast Asia.

The gains of the last sixty years came from yield rather than area, as world cereal yields roughly tripled from 1961, from about 1.4 to 4.1 tonnes a hectare, on not much more land. The gap between the best and worst systems remains vast: an Iowa maize farm harvests more than 11 tonnes a hectare, a typical farm in Sub-Saharan Africa less than 2, and closing that gap is where much of the next increase has to come from.

1c. Who Grows It

About 870 million people work in farming, roughly a quarter of the world's workforce, on about 600 million farms, five-sixths of them smaller than 2 hectares (5 acres). By one widely used estimate those smallholdings work only about 12% of the world's farmland yet grow about a third of its food, mostly in Asia and Africa, much of it for their own families and local markets.

At the other end are the industrial farms of the American Midwest, the Brazilian Cerrado, the Argentine Pampas, the Australian wheat belt, and the Black Sea steppe. They are mechanized, use inputs heavily, often cover thousands of hectares, and produce most of the grain that crosses borders.

About a fifth to a quarter of the world's food calories are traded internationally, and for importing countries that share is a large part of what they eat, which is why a few exporters and a few shipping chokepoints matter so much.

1d. The Water and Energy Inside Food

Agriculture takes about 72% of the fresh water the world withdraws, and food systems as a whole use about 30% of its energy, most of it off the farm in fertilizer, processing, refrigeration, and transport. A kilogram of wheat takes about 1,800 liters (475 US gallons) of water to grow, and a kilogram of beef about 15,000.

Synthetic nitrogen fertilizer, made from natural gas, is the largest single energy input, and Module 2 explains why so much of humanity depends on it. The food system is, in effect, an energy and water system that happens to produce calories, and every shock to gas, oil, or rain reaches the plate about one harvest later.

Module 1 Key Points

Foundations

• Rice and wheat each supply about a fifth of human calories; maize, the largest grain crop, is mostly feed and fuel.

• The world grows about 2.9 billion tonnes of grain and supplies about 3,000 kilocalories per person per day.

• Cereal yields roughly tripled since 1961 on similar land; Sub-Saharan Africa's yields are about a fifth of the United States'.

• About 600 million farms, five-sixths under two hectares; small farms grow about a third of food on 12% of farmland.

• About a fifth to a quarter of food calories cross borders, so a few exporters and chokepoints decide much.

• Agriculture takes 72% of fresh water withdrawals, and food systems use about 30% of the world's energy.

Module 1 Quiz

Check Your Understanding

1. What becomes of most of the world's maize?

A) Most is eaten as tortillas
B) It is exported to Africa as food aid
C) It becomes animal feed, ethanol, and starch
D) China buys most of it to hold in its state reserves for emergencies

2. Where did most of the world's extra food since 1961 come from?

A) Higher yields
B) Clearing new land in the tropics and the steppe
C) Imports from the Americas to the rest of the world
D) A smaller share of grain fed to animals

3. Who grows about a third of the world's food on about 12% of its farmland?

A) Industrial farms
B) State farms in China
C) Plantations in the tropics
D) Smallholders on farms under two hectares, mostly in Asia and Africa

4. About what share of the world's fresh water withdrawals goes to agriculture?

A) About a tenth
B) About 72%
C) Half
D) About a third, the same as industry

5. Why does the module call the food system an energy and water system?

A) Farms burn oil
B) It uses about 72% of fresh water withdrawals and about 30% of the world's energy, mostly off the farm
C) Energy firms own most farms
D) Crops are grown in flooded fields

Module 2 — A Brief History

From Malthus to the Price Crises

Recommended Reading / Reference

Book: Charles Mann, *The Wizard and the Prophet* (2018)

Book: Vaclav Smil, *Enriching the Earth: Fritz Haber, Carl Bosch, and the Transformation of World Food Production* (2001)

Book: Amartya Sen, *Poverty and Famines: An Essay on Entitlement and Deprivation* (1981)

Reference: FAO Food Price Index (monthly, from 1990); the Agricultural Market Information System (AMIS), *Market Monitor* (monthly)

Date	Event	Significance
c. 9500 BC	Wheat and barley domesticated in the Fertile Crescent; rice in China and maize in Mexico within a few thousand years	The first surplus, and with it cities and states
1798	Thomas Malthus, *An Essay on the Principle of Population*	Population outruns food, so famine checks numbers
1840	Justus von Liebig names nitrogen, phosphorus, and potassium as the nutrients plants need; the guano and nitrate trades follow	The nitrogen limit named
1845-52	The Irish famine: about a million dead and more than a million emigrants	The risk of a single crop
1879-84	The War of the Pacific: Chile takes the nitrate fields of Bolivia and Peru	A war fought over fertilizer
1909-13	Fritz Haber synthesizes ammonia; Carl Bosch scales it up at BASF, the German chemical company	The nitrogen limit broken
1930-33	The Soviet famine under collectivization: an estimated 5.7 to 8.7 million dead	Famine made by policy
1943	The Bengal famine: 2 to 3 million dead under wartime British rule	Sen's lesson that famine is about entitlement
1944-70	Norman Borlaug's dwarf wheat in Mexico; rice from the International Rice Research Institute (IRRI) in the Philippines; the Green Revolution in India and Pakistan	India's wheat harvest doubled in seven years
1959-61	China's Great Leap famine: most estimates 30 to 45 million dead	The deadliest famine in history
1972-74	Large Soviet grain purchases and a sharp rise in grain prices; famine in the Sahel	The world grain market turns political
1978	China begins returning farmland to households	Its famine cycle ends
1991	The Soviet Union collapses	The Black Sea becomes the wheat exporter
1996	Genetically modified soybeans and maize go on sale	The seed industry consolidates
2007-08	The first modern price crisis: rice nearly triples; food protests in dozens of countries	The system's first break
2010-11	Russia's drought and export ban; a record food price index in February 2011; the Arab Spring	The second break
2022	Russia invades Ukraine; the FAO Food Price Index peaks at 160.2 in March	The third break, and fertilizer as a strategic good
2026	War with Iran closes the Strait of Hormuz from February 28; fertilizer and gas prices jump	A fourth episode, still running in October 2026

The FAO Food Price Index is set at 100 for its 2014-16 average. Famine death tolls are ranges because no reliable count was kept.

2a. Malthus and the Nitrogen Limit

Thomas Malthus argued in 1798 that population grows geometrically while food grows only arithmetically, so famine would always check human numbers. For most of history he was close to right, and the reason was nitrogen: plants need it in bulk, and although the air is 78% nitrogen, almost none of it is in a form plants can use.

Farming was therefore limited by the fixed nitrogen that could be gathered from manure and legumes, supplemented in the nineteenth century by guano dug on Peruvian islands and by nitrate mined in the Atacama Desert. Chile fought Peru and Bolivia for the nitrate fields in the War of the Pacific of 1879-84.

In 1909 Fritz Haber synthesized ammonia from the nitrogen in air and from hydrogen under high pressure, and by 1913 Carl Bosch had scaled the process up at BASF. The Haber-Bosch process, now run mostly on natural gas, lifted the nitrogen limit off farming, and humans now fix about as much nitrogen each year as all the natural processes on land, most of it in fertilizer plants.

Jan Willem Erisman and colleagues estimated in 2008 that synthetic nitrogen fed 48% of the world's people, and that dependence is why the price of food now moves with the price of gas, a link Module 5 follows through the shocks of 2022 and 2026.

2b. The Green Revolution

From 1944 the American plant breeder Norman Borlaug, working in Mexico for the Rockefeller Foundation, bred short-stemmed, disease-resistant wheat whose dwarf plants could take heavy doses of fertilizer without falling over, so that yields doubled and then tripled. Rice followed from IRRI, whose first high-yielding variety, released in 1966, became known as 'miracle rice'.

The package of dwarf varieties, synthetic fertilizer, irrigation, and pesticides reached India and Pakistan in the mid-1960s, when famine there was widely predicted. India's wheat harvest more than doubled between 1965 and 1972, and by the late 1970s the country no longer depended on food aid. Borlaug won the Nobel Peace Prize in 1970 and is credited with saving hundreds of millions of lives.

The critics counted the costs: Punjab's aquifers are falling, irrigation without drainage has salted soils, crop diversity has narrowed, and the model depends on inputs that farmers must buy every season. Africa, with little irrigation and few rural roads, largely missed it.

Charles Mann frames the long argument as one between 'wizards', who trust technology to raise output, and 'prophets', who argue for living within ecological limits. Both camps have evidence on their side, and the argument between them runs through this course.

2c. Famine as Politics

The great famines of the twentieth century were made by governments more than by weather. Stalin's collectivization and grain requisitions caused the Soviet famine of 1930-33, which killed an estimated 5.7 to 8.7 million people, most of them in Ukraine and Kazakhstan.

In Bengal in 1943, wartime British policy, inflation, and hoarding let 2 to 3 million people die although the harvest was only modestly below normal. Mao's Great Leap Forward caused the deadliest famine in history in 1959-61, with most estimates putting the toll between 30 and 45 million, as officials requisitioned grain against inflated harvest reports.

Amartya Sen, who saw the Bengal famine as a boy, drew the lesson in *Poverty and Famines* (1981). Famines, he argued, are failures of entitlement, meaning people's ability to command food through work, trade, or transfers, rather than failures of supply. He later observed that no substantial famine has occurred in a functioning democracy with a free press, and Module 14 applies that test to Sudan and Gaza.

Reform reversed the pattern: China began handing farmland back to households in 1978, its grain output rose by about a third within six years, and its famine cycle ended. The Soviet collapse of 1991 eventually turned the Black Sea steppe from a grain importer into the source of more than a quarter of the world's wheat exports. Brazil's agronomists made the acid soils of the Cerrado farmable from the 1970s, which made Brazil the largest soybean exporter and China's main supplier of animal feed.

2d. The Price Crises

The modern system has broken three times, and a fourth episode is running. The first break came in 2007-08, when drought in Australia, oil above $100 a barrel, low stocks, and new American and European biofuel mandates that turned maize and vegetable oil into fuel pushed grain prices up for two years.

Then exporters panicked: India restricted rice exports from October 2007 and banned most of them in April 2008, Vietnam and others restricted theirs, and the Philippines, the largest importer, bought in a hurry. The export price of Thai rice, the benchmark, nearly tripled between late 2007 and May 2008, although the world's rice harvest had not failed.

Protests and riots over food prices broke out in dozens of countries, 48 by one count, from Haiti and Egypt to Bangladesh and Cameroon, and in Haiti the Senate dismissed the prime minister in April 2008 after a week of riots.

The second break followed quickly: drought and fires cut Russia's 2010 wheat harvest by a third, wheat prices rose by more than half in two months, and Russia banned grain exports from August 15. The FAO Food Price Index set a record in February 2011 that stood until 2022.

Bread prices were one of the grievances behind the uprisings in Tunisia and Egypt that began the Arab Spring that winter. The Group of Twenty (G20) major economies responded in 2011 by creating AMIS, which publishes shared data on crops and stocks so that rumor has less room to drive prices.

The third break came in 2022, when Russia's invasion of Ukraine closed Ukraine's ports and cut the world's largest fertilizer exporter off from many buyers, and the FAO index reached its all-time high of 160.2 in March 2022. The Black Sea Grain Initiative, brokered by the UN and Turkey, let about 33 million tonnes of Ukrainian food out before Russia quit it in July 2023, and record harvests elsewhere brought prices down.

Each break had the same shape: a supply shock in one breadbasket, amplified by export bans, energy prices, and thin stocks, landing hardest on poor importers who spend much of their income on food. Each was also political before it was agricultural, since mandates, bans, and an invasion were decisions, not droughts. The fourth episode began on February 28, 2026, when war with Iran closed the Strait of Hormuz to most shipping, and Module 5 follows it.

Module 2 Key Points

A Brief History

• Haber-Bosch ammonia, made mostly from natural gas, lifted farming's nitrogen limit and feeds nearly half the world's people.

• Borlaug's dwarf wheat doubled India's wheat harvest in seven years, and IRRI's rice followed; Africa, short of irrigation and roads, largely missed it.

• The great famines were political: Soviet 1930-33, Bengal 1943, China 1959-61. Sen showed famines are failures of entitlement, not supply.

• In 2007-08 biofuels, oil, thin stocks, and rice export bans nearly tripled Thai rice and set off food protests in dozens of countries.

• Russia's 2010 export ban led to a record index in February 2011; the 2022 invasion set the all-time high of 160.2.

• Every break was political before it was agricultural: one breadbasket's shock, amplified by bans, energy, and thin stocks, landing on poor importers.

Module 2 Quiz

Check Your Understanding

1. What did the Haber-Bosch process make possible?

A) Breeding short-stemmed wheat that resists falling over
B) Mining phosphate rock on an industrial scale
C) Making ammonia from the nitrogen in air
D) Refrigerated shipping of grain and meat across oceans

2. What is Amartya Sen's account of famine?

A) A failure of people's entitlement to command food
B) A collapse in harvests caused by drought
C) Population outgrowing the food supply, as Malthus predicted
D) A consequence of speculation in grain futures by traders

3. Why did the export price of Thai rice nearly triple in 2007-08?

A) Asia's rice harvest failed after a drought
B) Biofuel plants began buying rice for fuel
C) A typhoon closed Thailand's ports for several months that spring
D) Export bans by India and others set off panic buying

4. What did the G20 create in 2011 in response to the price crises?

A) A world grain reserve held by the FAO
B) A tax on speculation in grain futures
C) A shared information system on crops and stocks, called AMIS
D) A fund to buy fertilizer for poor importers

5. What shape did the 2008, 2011, and 2022 crises share, on the module's account?

A) A harvest failure in every region at once
B) A recession that cut demand
C) A collapse of the dollar that raised every commodity price together
D) A shock in one breadbasket, amplified by bans and energy prices

Module 3 — The Grains

Wheat, Maize, and Rice, With the Numbers

Recommended Reading / Reference

Reference: USDA, WASDE (monthly; the September and October 2026 editions); USDA Foreign Agricultural Service, *Grain: World Markets and Trade* (monthly); International Grains Council (IGC), *Grain Market Report*; AMIS, *Market Monitor*

3a. Wheat

Country or region	Production (Mt)	Exports (Mt)	Imports (Mt)	Note
China	141.0	1.0	6.0	The largest producer; holds 120 Mt of stocks
European Union	133.8	31.0	6.5	France, Germany, Poland, Romania
India	121.0	2.0	0.1	A record harvest; exports allowed again from August 24, 2026
Russia	88.0	40.0	0.3	The largest exporter; exports cut in October to a five-year low
United States	41.7	20.4	3.8	1.53 billion bushels, down more than a fifth from 2025
Canada	36.5	30.0	0.7	Spring wheat and durum
Australia	31.0	23.5	0.2	Rain-fed, and exposed to El Niño
Ukraine	26.0	12.5	0.1	Its deep-water ports closed by attacks
Argentina	21.5	15.5	—	Harvested in December and January
Kazakhstan	15.0	9.5	1.5	Ships by rail to Central Asia and Iran
North Africa	23.1	2.0	27.6	Egypt, Algeria, and Morocco among the largest buyers
Middle East	23.2	0.7	19.7	Iran, Iraq, Saudi Arabia, Yemen, and the Gulf states
Southeast Asia	—	1.6	31.4	Indonesia, the Philippines, Vietnam, Thailand
World	822.4	209.0	—	Down from a record 844.0 Mt in 2025/26; ending stocks 276 Mt

USDA projections for the 2026/27 marketing year (mid-2026 to mid-2027 for most countries): the September 2026 WASDE, with the October 9 changes for the United States, Canada, Russia, and world exports. Mt is million metric tonnes; a tonne of wheat is 36.7 bushels or 1.10 US short tons.

Wheat is the bread and noodle grain of about a third of humanity, and the world grows about 822 million tonnes in 2026/27 by USDA's projection, down from a record 844 million the year before. China, the European Union, and India grow the most, but China and India eat nearly all of theirs.

The export market of about 209 million tonnes belongs to a handful of countries: Russia, the European Union, Canada, Australia, the United States, Argentina, Ukraine, and Kazakhstan. The buyers are North Africa, the Middle East, Southeast Asia, and much of Sub-Saharan Africa, which is why a Black Sea disruption is a problem in Cairo and Lagos.

Prices rose through 2026, as the American crop shrank by more than a fifth, Russia's exports fell to a five-year low, and attacks closed Ukraine's deep-water ports from July (Module 16). American hard red

winter wheat, a benchmark, averaged $347 a tonne in September 2026, against $243 for 2025 as a whole (World Bank).

3b. Maize

Country	Production (Mt)	Exports (Mt)	Imports (Mt)	Note
United States	407.3	83.2	0.6	16.0 billion bushels at 181.2 bushels an acre; about a third goes to ethanol
China	307.0	—	5.0	Holds 165 Mt of stocks
Brazil	139.0	43.0	1.8	Most of it a second crop sown after soybeans
Argentina	55.0	38.0	—	
European Union	48.0	1.6	23.5	Cut in October after the summer drought
Ukraine	31.8	22.0	—	Ships by the Danube and rail while Odesa is closed
Mexico	24.6	—	27.2	The largest importer; banned planting of genetically modified (GM) maize in 2025
South Africa	16.5	2.2	—	Southern Africa's granary; exposed to El Niño
Japan, South Korea, Egypt	—	—	15.5, 11.5, 13.2	Feed importers
World	About 1,295	210.1	—	Down from a record 1,331 Mt in 2025/26; ending stocks 280 Mt

USDA projections for 2026/27: the September 2026 WASDE, with the October 9 figures for the United States, the European Union, and world stocks. A tonne of maize is 39.4 bushels.

Maize is the largest grain crop by weight, about 1.3 billion tonnes, and most of it is not eaten by people but becomes animal feed, ethanol, sweeteners, and starch. The United States grows almost a third of it, and USDA's October 9 report raised the American crop to 16.0 billion bushels, which sent futures briefly down by the daily limit.

The United States, Brazil, Argentina, and Ukraine export most of what is traded, while China grows a quarter of the world's maize and holds about three-fifths of its stocks. Mexico, Japan, South Korea, Egypt, and the European Union are the large buyers, and Mexico's ban on growing GM maize, written into its constitution in 2025, still lets it import American GM grain after a trade panel ruled against its earlier restrictions in December 2024.

3c. Rice

Country	Production (Mt, milled)	Exports (Mt)	Imports (Mt)	Note
India	147.0	25.0	—	The largest exporter: record exports, about 40% of trade; holds 55.5 Mt of stocks
China	147.0	2.2	4.0	Holds 107 Mt of stocks
Indonesia	33.6	—	0.5	Aiming at self-sufficiency
Vietnam	26.1	8.1	3.6	Exports fragrant rice and imports cheaper grades
Thailand	20.3	7.5	—	The benchmark price; jasmine rice

Country	Production (Mt, milled)	Exports (Mt)	Imports (Mt)	Note
Philippines	12.4	—	5.6	The largest importer
Burma and Pakistan	11.0 and 9.6	2.1 and 5.0	—	Pakistan sells basmati
Japan	7.4	—	0.7	Prices doubled in 2024-25; the government released reserve rice
Nigeria	5.7	—	2.9	West Africa's largest buyer
United States	5.0	2.5	1.6	Arkansas, Louisiana, California
World	533.9	62.6	—	About 12% of the crop is traded; ending stocks 197 Mt

USDA projections for 2026/27 (September 2026 WASDE). Milled rice is about two-thirds of the weight of unhusked paddy.

Rice is the staple of about half the world, grown overwhelmingly in Asia, and India and China grow about 147 million tonnes each, together more than half the world's crop. Only about 12% crosses a border, which makes the market thin, and India alone supplies about 40% of what is traded.

Governments intervene more in rice than in any other grain because it is the poor world's staple and its trade is thin. India's export bans of 2022-24 sent prices to their highest since 2008, and its decision to lift them in 2024-25 brought them down (Module 13). Thai 5% broken rice, the benchmark, averaged $482 a tonne in September 2026, against $408 for 2025 (World Bank).

3d. The 2026/27 Balance

The 2025/26 season brought record crops of wheat and maize, so the world entered 2026 with comfortable stocks. For 2026/27 USDA projects smaller wheat, maize, and rice crops and ending stocks of 276 million tonnes of wheat and 280 million of maize, about a third of a year's use of wheat and a fifth of maize.

Much of that cushion is not available to the market, because China holds about 44% of the world's wheat stocks, three-fifths of its maize, and more than half of its rice, and it does not sell them abroad. Stocks outside China are what importers can actually buy, and they are thinner than the headline totals suggest.

The market's reading in October 2026 is that supply is adequate in total and exposed in particular places. Ukraine's ports are closed, Gulf fertilizer is constrained by the war with Iran, and a strong El Niño threatens Australia, India, and southern Africa (Module 11), and every previous crisis showed that adequate world totals and local catastrophe can coexist.

Module 3 Key Points

The Grains

• The world grows about 822 Mt of wheat in 2026/27, below 2025/26's record 844 Mt; Russia leads exports, at a five-year low of 40 Mt.

• Maize, about 1.3 billion tonnes, is mostly feed and fuel; the US grows almost a third, and Mexico is the largest importer.

• Rice is thin: about 12% is traded, and India supplies about 40% of exports, a record 25 Mt projected for 2026/27.

• China holds about 44% of world wheat stocks, three-fifths of maize, and over half of rice, none of it for sale abroad.

• Supply is adequate in total but exposed at Ukraine's ports, Gulf fertilizer, and El Niño's path; totals and local catastrophe coexist.

Module 3 Quiz

Check Your Understanding

1. Who is the largest wheat exporter in 2026/27, by USDA's projection?

A) Russia, at about 40 Mt
B) The European Union, at about 31 Mt
C) India
D) The United States, at about 20 Mt after a small harvest

2. Which country is the largest importer of maize in 2026/27?

A) China, which buys to refill its reserves
B) Mexico
C) Japan, for its feed industry
D) The European Union, after its harvest was cut

3. Why is the rice market described as thin?

A) Rice spoils quickly
B) Only about 12% crosses borders, and India supplies 40% of that
C) Rice is traded only between governments
D) Most rice grows in floodplains where harvests fail every few years, so stocks are always low

4. What share of the world's maize stocks does China hold, by USDA's projection for 2026/27?

A) About a tenth
B) Under 5%, since it imports instead
C) About three-fifths, roughly 165 of 280 million tonnes
D) About a quarter

5. What does the module conclude about the 2026/27 balance?

A) Adequate in total, exposed in particular places
B) A global shortage of grain in every importing region this year
C) A surplus so large that prices fall below the cost of production
D) Too uncertain to assess until the Southern Hemisphere harvest arrives

Module 4 — Oilseeds, Sugar, and the Soft Commodities

The Crops That Compete for Food, Feed, and Fuel

Recommended Reading / Reference

Reference: USDA Foreign Agricultural Service, *Oilseeds: World Markets and Trade* (monthly) and *Coffee: World Markets and Trade* (July 2026); International Cocoa Organization (ICCO), *Quarterly Bulletin of Cocoa Statistics* (August 2026); International Sugar Organization (ISO), *Quarterly Market Outlook*; World Bank, *Commodity Price Data* (the Pink Sheet, monthly)

4a. Soybeans and the China Pipeline

Country	Production (Mt)	Exports (Mt)	Imports (Mt)	Crushed (Mt)	Note
Brazil	186.0	118.0	0.8	65.0	The largest producer since 2019/20 and the largest exporter
United States	124.2	46.1	0.7	75.7	A record 4.56 billion bushels at 53.1 bushels an acre
Argentina	50.0	6.5	6.5	43.0	The largest exporter of soybean meal and oil
Paraguay	11.1	7.4	—	3.6	Ships down the Paraná River
China	21.0	0.1	115.0	111.0	About 60% of world imports, for the largest pig herd
European Union	2.8	0.3	13.7	14.9	Imports beans and meal for feed
Southeast Asia and Mexico	0.7	—	11.6 and 6.8	13.2	Feed for poultry, pigs, and fish
World	About 443	191.6	—	—	A record; 302 Mt of meal and 75 Mt of oil; ending stocks 124 Mt

USDA projections for 2026/27: the September 2026 WASDE, with the October 9 figures for the United States and world stocks. A tonne of soybeans is 36.7 bushels.

The world grows a record of about 443 million tonnes of soybeans in 2026/27 by USDA's projection, and crushing turns about four-fifths of each bean's weight into meal, the protein in animal feed, and most of the rest into oil for cooking and, increasingly, fuel. Brazil overtook the United States as the largest producer in 2019/20 and now exports more than twice as much.

China imports about 115 million tonnes, some 60% of world trade, to feed the world's largest pig herd. When the 2025 trade war stopped Chinese purchases of American beans, Brazil took the trade, and Washington paid farmers $12 billion of emergency aid. At Busan in October 2025 China agreed to buy at least 25 million tonnes of American soybeans a year in 2026-28, and Module 13 follows how far it has kept that promise.

The oilseed complex is where food, feed, and fuel compete most directly for one crop, because American biodiesel and renewable diesel, supported by federal fuel mandates and tax credits, now take about half of the country's soybean oil.

4b. The Vegetable Oils

Oil	Production	Leading producers	Leading importers	Uses and 2026 notes
Palm	Nearly 80 Mt	Indonesia (45.0 Mt) and Malaysia (19.6 Mt), about four-fifths of the total	India, China, Pakistan, the EU	Cooking oil for Asia, processed food, and biodiesel; Indonesia, on a 40% biodiesel blend (B40) since 2025, announced in June 2026 that a 50% blend (B50) would start in July; USDA cut its Indonesian forecast by 2.2 Mt on October 9
Soybean	75.1 Mt	China (from imported beans), the US, Brazil, Argentina	India, North Africa	Cooking oil and American renewable diesel
Rapeseed and canola	About 33-35 Mt	The EU, Canada, China, India, Australia	The EU, China	Cooking oil and European biodiesel; China cut its tariff on Canadian canola seed in 2026
Sunflower	About 20-22 Mt	Ukraine and Russia, more than half together	India, the EU, Turkey	The Black Sea's oil
Olive	About 3 Mt	Spain (about two-fifths), Italy, Greece, Tunisia	The US, the EU	Spain's drought halved its 2023 crop and tripled prices
All vegetable oils	243.2 Mt			USDA's October 9, 2026 forecast for 2026/27

Marketing year 2026/27. Palm and total figures from USDA's October 9, 2026 report; soybean oil from the September 2026 WASDE; the others rounded from USDA's 2026 estimates.

Palm oil is the cheapest vegetable oil and the most traded, and Indonesia and Malaysia produce about four-fifths of it, in some of the world's most biodiverse forests, which makes it the main target of Europe's deforestation rules (Module 10). Indonesia uses its own palm oil to cut diesel imports, and each step up in its biodiesel blend removes millions of tonnes from export.

Prices in 2026 reflect that pull: the FAO's vegetable oil index stood at 198.6 in September 2026, against a peak of about 252 in March 2022. The World Bank's September averages were $1,180 a tonne for palm oil delivered to northwest Europe and $1,615 for crude soybean oil at Dutch mills.

4c. Sugar, Coffee, Cocoa, and Cotton

Commodity	Production	Leading producers	Price story	Structure
Sugar	About 180-190 Mt a year: the ISO expects 180 Mt in 2026/27; USDA put 2025/26 at a record 189 Mt	Brazil (about 42-44 Mt in 2026/27), India (about 32 Mt), the EU, Thailand, China	$0.41 a kilogram (18.6 cents a pound) in September 2026; the FAO's sugar index rose 6.1% that month, and El Niño threatens the Indian and Thai crops	Brazil's mills switch cane between sugar and ethanol, and India's export limits swing the market
Coffee	A record 189.7 million 60-kilogram bags forecast for 2026/27, up from 178.8 million	Brazil (71.9 million bags), Vietnam (32.5), Colombia (13.4), Ethiopia (12.1), Indonesia (11.4)	Arabica averaged $7.26 a kilogram ($3.29 a pound) in September 2026, against $8.47 for 2025, after records above $4 a pound	About 12.5 million farms, most of them small, sell to a few traders and roasters

Commodity	Production	Leading producers	Price story	Structure
Cocoa	4.73 Mt in 2024/25, a surplus of 37,000 t; the ICCO withheld its 2025/26 figures	Côte d'Ivoire (about two-fifths), Ghana, Ecuador, Cameroon, Nigeria	New York futures passed $12,000 a tonne in December 2024; the World Bank average was $5,920 in September 2026, against $7,800 for 2025	Two West African states, millions of smallholders, and a few grinders; a new International Cocoa Agreement took effect on October 1, 2026
Cotton	117.3 million 480-pound bales, about 25.5 Mt, in 2026/27	China (33.5 million bales), India (24.0), Brazil (18.5), the US (13.2)	Prices subdued by ample stocks	Brazil (15.5 million bales) out-exports the US (12.3); the US bars cotton from Xinjiang

Sources: ISO (May 2026); USDA Foreign Agricultural Service (July 2026 for coffee); the September 2026 WASDE for cotton; ICCO (August 2026); World Bank Pink Sheet (October 2026).

The soft commodities share a structure: millions of smallholders in a few tropical countries grow them, a handful of traders and processors buy them, and rich countries consume most of them, while the climate grows less reliable for all of them.

Cocoa showed the risk when swollen-shoot virus, aging trees, illegal gold mining, and erratic rain cut West African harvests, and New York cocoa futures passed $12,000 a tonne in December 2024, four times their level of early 2023. High prices then did what high prices do: chocolate makers ground less cocoa, a surplus returned in 2024/25, and the World Bank's average fell to $5,920 a tonne by September 2026.

Coffee followed a similar path, as drought in Brazil sent arabica to records in 2025, and USDA now forecasts a record world crop for 2026/27, which has pulled prices down. Research projects that the land suitable for arabica could shrink by about half by 2050 if emissions stay high, so these spikes are likely to recur.

Sugar is the most policy-distorted of the markets, because Brazil's mills choose between sugar and ethanol according to relative prices and fuel policy, and India's export controls can add or remove millions of tonnes. Cotton is a story of water, of sanctions over forced labor in Xinjiang, and of competition from polyester, and Brazil overtook the United States as its largest exporter in 2023/24.

Module 4 Key Points

Oilseeds, Sugar, and the Soft Commodities

• Soybeans, a record of about 443 Mt in 2026/27, are crushed into meal for feed and oil for food and fuel; Brazil exports 118 Mt.

• China imports about 115 Mt, 60% of world trade, and agreed at Busan to buy 25 Mt of US soybeans a year.

• Fuel mandates take about half of US soybean oil; Indonesia, on B40 since 2025, announced B50 for July 2026.

• Cocoa passed $12,000 a tonne in December 2024 and averaged $5,920 in September 2026; coffee expects a record 2026/27 crop.

• The softs share a structure: tropical smallholders, a few traders and roasters, rich-world consumers, and rising climate risk.

Module 4 Quiz

Check Your Understanding

1. How much of world soybean imports does China take, by USDA's 2026/27 projection?

A) About a tenth, since it grows most of its own
B) Nearly all, about 95%
C) About a third, with Europe taking the rest
D) About 60%, some 115 Mt

2. Why does the module say food, feed, and fuel compete most directly in the oilseed complex?

A) Soybeans cannot be stored
B) Meal and oil are sold to the same buyers
C) Fuel mandates now take about half of American soybean oil
D) Crushers must sell their oil to governments at fixed prices set each year by treaty

3. Which country is the largest exporter of cotton?

A) The United States, which grows the most
B) China, from Xinjiang
C) India, after its 2026 harvest
D) Brazil

4. What happened to cocoa prices after their 2024 peak?

A) They kept rising
B) They fell back, averaging about $5,900 a tonne in September 2026 against more than $12,000 at the 2024 peak
C) They were fixed by the new treaty
D) They doubled again in 2025

5. What does USDA forecast for world coffee production in 2026/27?

A) A record, about 190 million bags
B) A fall of a third
C) Unchanged from 2025/26, at about 179 million bags
D) A deficit large enough to push prices above their 2025 records

Module 5 — Fertilizer

The Natural Gas Inside Food

Recommended Reading / Reference

Report: International Trade Centre (ITC), with the World Trade Organization and UN Trade and Development, analysis of trade through the Strait of Hormuz (August 4, 2026)

Reference: International Fertilizer Association (IFA) statistics; World Bank, Pink Sheet (monthly); DTN, weekly US retail fertilizer prices; Saloni Shah, 'Sri Lanka's Experiment With Organic Farming Fails Miserably' (Breakthrough Institute, March 2022)

5a. N, P, and K

Nutrient	Source	World use	Leading producers	Leading exporters	Leading importers	Chokepoint
Nitrogen (N): urea, ammonia, liquid urea ammonium nitrate (UAN)	Ammonia made from natural gas, which is 70-90% of the cost of urea	About 110 Mt of N a year	China, India, Russia, the US, the Gulf	Russia, Qatar, Saudi Arabia, Oman, Egypt, Iran	Brazil, India, the US, Australia, Turkey	The Strait of Hormuz
Phosphate (P): diammonium phosphate (DAP) and mon oammonium phosphate (MAP)	Mined phosphate rock and sulfuric acid	About 50 Mt of phosphorus pentoxide (P_2O_5)	China, Morocco, the US, Russia, Saudi Arabia	Morocco, Russia, Saudi Arabia, China (when allowed)	Brazil, India, Pakistan, Australia	Morocco's reserves; China's export curbs; Gulf sulfur
Potash (K): potassium chloride	Mined from old seabeds	About 40 Mt of potassium oxide (K_2O)	Canada, Russia, Belarus, China, Israel	Canada, Russia, Belarus	Brazil, China, the US, India, Indonesia	Three countries mine about 70%; Belarus under sanctions since 2021

Rounded IFA estimates for the early 2020s. Phosphate and potash are counted by their oxide content, the industry convention.

Plants need three nutrients in bulk: nitrogen comes from ammonia made by the Haber-Bosch process, in which natural gas is both feedstock and fuel and accounts for 70-90% of the cost of urea, the most common nitrogen fertilizer. Phosphorus comes from mined phosphate rock, of which Morocco holds about 70% of known reserves, and potassium comes from potash mined mainly in Canada, Russia, and Belarus.

Nitrogen must be applied every season, while phosphate and potash persist in the soil for longer, so nitrogen is where shocks bite first. About half of all fertilizer is used in the country that makes it, while the half that is traded passes through a few chokepoints, so a problem in one place ripples everywhere.

5b. Who Makes It and Where It Moves

Fertilizer follows cheap gas: the Gulf states turn gas that costs them little into urea and ammonia for export, and Russia is the largest exporter of fertilizer overall and, with Belarus, a giant in potash. The United States, on shale gas, makes most of what it uses, and China, more self-sufficient still, restricts exports to protect its own farmers. OCP, the Moroccan state company, dominates phosphate, and Canada's Nutrien is the largest producer of potash.

The great importers are Brazil, which buys most of the fertilizer for its soybeans and maize abroad, and India, which subsidized fertilizer for its farmers at a cost of about $20 billion a year before the 2026 shock. Southeast Asia, Africa, and Europe also import, and Europe's own nitrogen industry closed or curtailed much of its capacity when gas prices spiked in 2022.

5c. The 2022 Shock and Sri Lanka

Russia's invasion of Ukraine in 2022 disrupted Russian and Belarusian potash and much Russian nitrogen, while European gas prices made European ammonia uneconomic. Urea from the Middle East averaged $925 a tonne in April 2022 by the World Bank's count, about four times its level two years earlier. Farmers in Africa and South Asia applied less, and prices took about two years to come back down.

Sri Lanka had already shown what happens when fertilizer is withdrawn on purpose: in April 2021 President Gotabaya Rajapaksa banned imports of synthetic fertilizer and pesticides to make the country's farming organic, amid a shortage of foreign currency. Rice output fell by about 20% in the first six months, rice prices rose by about half, the country spent about $450 million importing rice, and the tea crop, its main export, suffered losses of about $425 million.

The government lifted the ban for tea, rubber, and coconut in November 2021 and suspended it for other key crops in early 2022, but the damage fed an economic collapse. Sri Lanka defaulted on its foreign debt in 2022, and mass protests drove Rajapaksa from office in July, a demonstration that the Green Revolution's inputs cannot be withdrawn without withdrawing its yields.

5d. The 2026 Hormuz Shock

Period	What happened	Urea, Middle East ($/t, quarterly average)
Late 2025	Before the war	398.7 (fourth quarter)
Early 2026	American and Israeli strikes on Iran on February 28; Iran declares the Strait of Hormuz closed; Qatar halts its gas-export plants on March 2; urea plants in India and Bangladesh cut output for lack of gas	537.7 (first quarter)
Spring 2026	Ceasefire on April 7-8 and a US blockade of Iran's ports from April 13; urea exports from Hormuz-dependent states fall 83% in April from a year earlier; the urea benchmark peaks above $850 a tonne in April; passage restored for talks on June 17	693.5 (second quarter)
Summer 2026	Tanker strikes on July 7-8 end the June agreement; China relaxes its urea export limits; northern planting ends; Brazil delays purchases	399.2 (third quarter); 407.5 in September
October 2026	Iran says the strait stays closed until its conditions are met, and a record ten tankers were struck in the week to October 4; American farmers still pay more than a year earlier: urea $683 per short ton (up 12%), anhydrous ammonia $979 (up 20%)	US retail prices: DTN, week to October 2

Urea prices: World Bank Pink Sheet (prilled urea, free on board, Middle East), October 2026. Trade figures: ITC, August 4, 2026. A short ton is 2,000 pounds, or 0.907 tonnes.

Before the war, producers that depend on the Strait of Hormuz, chiefly Qatar, Saudi Arabia, Iran, Bahrain, Kuwait, and the United Arab Emirates (UAE), shipped about 43% of the world's seaborne urea, 44% of its seaborne sulfur, and more than a quarter of its ammonia. The war that began on February 28, 2026 cut those flows at once, and the ITC found that urea exports from Hormuz-dependent economies were 83% lower in April 2026 than a year earlier.

Nitrogen moved sharply while potash and phosphate moved less, because urea and ammonia are concentrated in the Gulf and potash is not. Indian and Bangladeshi urea plants cut output in March as Qatari gas stopped arriving, and the World Bank's average price of Middle Eastern urea rose from $399 a tonne in late 2025 to $694 in the second quarter of 2026.

The spike then faded faster than in 2022, because China relaxed its limits on urea exports, the Northern Hemisphere's planting season ended, and Brazil postponed its purchases, so the world price was back near $400 by August and September. The strait itself did not stay open, since the June agreement collapsed in July, and analysts cited by the ITC expect fertilizer prices to stay high into at least early 2027.

Worked example — From Gas Price to Bread Price

A tonne of urea takes about 22-24 million British thermal units (MMBtu) of natural gas, so at about $3 per MMBtu, the American Henry Hub price in early October 2026, the gas in a tonne costs about $70. At Europe's price of about $26 it costs more than $550, which is why European plants struggle while Gulf and American plants run. A wheat farmer on the US Plains might apply 100 kilograms of nitrogen a hectare, about 217 kilograms of urea, for a yield of 3 tonnes a hectare (45 bushels an acre). At September 2026's price of $347 a tonne for American hard red winter wheat, that crop is worth about $1,040 a hectare. Urea at the world price of about $400 a tonne costs $87 a hectare, about 8% of the crop's value, and at the second quarter's $694 it costs $151, about 15%. At the American retail price of $683 a short ton ($753 a tonne) it costs $164, about 16%. Farmers respond by applying a little less, which near the usual rate costs only a few percent of yield, or by switching to soybeans, which make their own nitrogen. Across the world's 220 million hectares of wheat, a 5% fall in yield would be about 40 million tonnes, a fifth of world trade. The chain from a closed strait to a dearer loaf runs from gas to urea in weeks, to planting decisions in a season, to the harvest six to nine months later, to grain prices as the harvest data arrive, and to bread three to six months after that.

Module 5 Key Points

Fertilizer

• Nitrogen comes from gas, phosphate from rock (Morocco holds about 70% of reserves), and potash from Canada, Russia, and Belarus.

• Before the war, Hormuz-dependent producers shipped about 43% of seaborne urea, 44% of seaborne sulfur, and over a quarter of ammonia.

• Their urea exports fell 83% in April 2026; the World Bank's urea average rose from $399 in late 2025 to $694 in the second quarter.

• China's renewed exports and the end of spring planting cut urea to about $400 by September; US farm prices stayed higher.

• Sri Lanka's 2021 ban on synthetic fertilizer cut rice output 20% in six months and fed the economic collapse of 2022.

• Fertilizer works with a lag, through planting, harvest, and shelves, so a spring shock reaches food prices months later.

Module 5 Quiz

Check Your Understanding

1. Why did nitrogen prices jump in 2026 while potash moved much less?

A) Potash is made from gas
B) Farmers stopped buying nitrogen
C) Canada stopped exporting potash
D) Much of the world's traded urea and ammonia ships from the Gulf through Hormuz, while potash comes from Canada, Russia, and Belarus

2. What share of seaborne urea exports came from Hormuz-dependent producers before the war?

A) About 43%
B) Under 5%
C) About two-thirds, since Qatar alone exported half
D) About 10%, with most urea made in China and Russia

3. What happened to Sri Lanka's rice output in the first six months after its 2021 fertilizer ban?

A) It rose, as organic methods restored the soil
B) It was unchanged, because farmers used stored fertilizer
C) It fell 20%
D) It doubled after subsidies for compost were paid

4. In the worked example, why do European fertilizer plants struggle in 2026?

A) They lack ammonia
B) Gas at about $26 per MMBtu makes their urea cost several times America's
C) Their plants are too new
D) They must pay for imported potash and phosphate rock at prices fixed by Morocco and Canada

5. Why does a fertilizer shock reach food prices with a lag?

A) Fertilizer prices are fixed by contract for five years
B) Fertilizer goes on at planting, so its effect shows in the harvest months later and in the shops after that
C) Governments store fertilizer for a decade
D) Farmers ignore prices until the next election

Module 6 — Seeds, Chemicals, and Machines

The Input Industry, and How to Regulate Gene Editing

Recommended Reading / Reference

Report: US National Academies of Sciences, Engineering, and Medicine, *Genetically Engineered Crops: Experiences and Prospects* (2016)

Report: ETC Group, *Food Barons 2022*

Reference: The EU regulation on plants obtained by new genomic techniques (adopted 2026); company reports from Bayer, Corteva, Syngenta Group, BASF, and Deere

6a. Seeds

Seed was saved on the farm for ten thousand years and became an industry in the twentieth century. The first step was the hybrid: maize crosses whose vigor does not carry into the next generation, so farmers buy new seed every year. The second was genetic modification (GM), which from 1996 inserted genes from other organisms to give maize, soybeans, cotton, and canola tolerance of herbicides and resistance to insects.

Mergers then concentrated the industry: Dow and DuPont merged in 2017 and spun off their farm business as Corteva in 2019, the Chinese state company ChemChina bought Syngenta in 2017, and Bayer bought Monsanto in 2018. By the ETC Group's 2022 count, Bayer and Corteva together sold about 40% of the world's commercial seed, and four firms sold about 62% of its pesticides.

Company	Home and owner	Seeds and traits	Chemicals	2026 note
Bayer Crop Science	Germany; listed	Dekalb maize, Asgrow soybeans, Monsanto's traits	Glyphosate (Roundup), other herbicides, fungicides	Won *Monsanto v. Durnell*, its glyphosate case at the US Supreme Court, on June 25, 2026; proposed a $7.25 billion class settlement in February
Corteva	United States; listed	Spun off on October 1, 2026 as Vylor, which kept the Pioneer brand	Herbicides, insecticides, and biological products	Now a crop-protection company only
Syngenta Group	Switzerland; owned by China's state-owned Sinochem	Maize, soybean, and vegetable seed	The largest seller of farm chemicals, with Adama's generics	Withdrew a planned Shanghai listing in 2024
BASF Agricultural Solutions	Germany; part of BASF	InVigor canola, Nunhems vegetables	Herbicides and fungicides, including units bought from Bayer in 2018	Being prepared for a stock-market listing by 2027
KWS, Limagrain, Sakata, Rijk Zwaan	Germany, France, Japan, Netherlands; family or cooperative	Sugar beet, wheat, maize, vegetables	Little	The independent breeders
Longping High-Tech, Beidahuang, and other Chinese firms	China; state-linked	Hybrid rice; GM maize since 2023-24	Generic chemicals from Chinese plants	Seed treated as food-security policy

GM traits now dominate the crops they were made for: more than 90% of American maize, soybeans, and cotton are genetically modified, as are most of Brazil's and Argentina's. Europe grows almost none but

imports about 30 million tonnes of mostly GM soybeans and meal a year as animal feed. India permits only GM cotton, and China, which resisted for two decades, began approving GM maize and soybeans in 2023-24 as food-security policy.

Gene editing is the newer tool: methods such as CRISPR, a gene-editing tool adapted from bacteria, change a plant's own genes, often by a few letters of DNA, without inserting genes from another species. Most countries have decided to treat simple edits more lightly than GM, and the European Union (EU) joined them in 2026.

Country or bloc	GM crops grown	GM share	Rules for gene-edited crops	Note
United States	Maize, soybeans, cotton, canola, sugar beet, alfalfa	Over 90% of maize, soybeans, and cotton	Most edits without foreign DNA escape GM rules; a federal court struck down the Agriculture Department's 2020 rule in December 2024	Where GM farming began
Brazil	Soybeans, maize, cotton, sugarcane	Over 90% of soybeans, maize, and cotton	Case by case since 2018; most edits treated as conventional	Approved GM drought-tolerant wheat in 2023
Argentina	Soybeans, maize, cotton, wheat	Nearly all soybeans and maize	The first framework for edited crops, 2015	Developed a drought-tolerant GM wheat
India	Cotton only	Over 90% of cotton	Simple edits exempted in 2022; two edited rice varieties released in May 2025	GM mustard approved in 2022, stalled in the courts
China	Cotton and papaya; maize and soybeans from 2023-24	Rising	Guidelines in 2022; edited soybeans (2023) and wheat (2024) approved	Food security first
European Union	Almost none	Imports about 30 Mt of GM feed a year	New genomic techniques (NGT) regulation adopted in 2026, applying from mid-2028	Grows none, feeds plenty
England	None	—	Precision Breeding Act 2023; its rules for plants took effect in November 2025	Diverged from the EU after Brexit
Sub-Saharan Africa	South Africa (maize, soybeans, cotton); Nigeria, Kenya, Ghana, Malawi (cotton, cowpea, maize)	South Africa high, others small	Nigeria, Kenya, Ghana, and Malawi exempt most simple edits	Pest-resistant cowpea in Nigeria and Ghana

Worldwide, GM crops covered about 190 million hectares (470 million acres) in 29 countries in 2019, the last global count by ISAAA, the industry-funded International Service for the Acquisition of Agri-biotech Applications.

6b. Chemicals

Herbicides, insecticides, and fungicides form a market of roughly $70-80 billion a year, sold by the same few companies, while Chinese factories make most of the world's generic active ingredients. Use per hectare is highest in Latin America and East Asia and rising in Africa, and resistance is the industry's treadmill: dozens of weed species now survive glyphosate, so farmers stack herbicides and companies stack traits.

Glyphosate, sold by Monsanto as Roundup, is the world's most used herbicide and the subject of the largest farm-chemical litigation in history, brought by plaintiffs who claim it causes non-Hodgkin lymphoma. The World Health Organization's cancer agency called it probably carcinogenic in 2015, while the US

Environmental Protection Agency (EPA) and the EU's regulators judged it unlikely to cause cancer, and the EU renewed its approval for ten years in 2023.

Bayer has paid more than $10 billion to settle claims since 2020, and in February 2026 it proposed a $7.25 billion class settlement for future claims. On June 25, 2026 the Supreme Court ruled 7-2 that federal pesticide law preempts state lawsuits faulting Monsanto for not warning of cancer, in a case brought by John Durnell of Missouri. Europe goes further than America on other chemicals: it banned outdoor use of three neonicotinoid insecticides in 2018 because of their effect on bees.

6c. Machines and Data

Deere, the world's largest maker of farm machinery, ahead of CNH, AGCO, Kubota, and Claas, saw its net sales and revenues fall from $61 billion in fiscal 2023 to $45.7 billion in fiscal 2025 as the farm economy turned down. Its tractors steer by satellite, its planters place seed to the centimeter, and its See & Spray machines use cameras to spray weeds rather than whole fields.

Deere reported that See & Spray cut herbicide use by an average of 59% across more than a million acres in 2024. Its data platform knows more about many American fields than the farmers who own them, which has made data ownership and the right to repair political fights, and the US Federal Trade Commission (FTC) sued Deere in January 2025 over its repair restrictions.

Precision tools pay where farms are large and capital is cheap, so they are standard on big farms in the Americas, Europe, and Australia and nearly absent from the world's 500 million smallholdings, where the yield gap is widest.

6d. Concentration

A few firms sell most of the seed and chemicals, a few trade most of the grain (Module 7), and a few process most of the meat. Facing them are about 600 million farms, and the imbalance is one reason farmers keep the thinnest margins in the chain. The US farmer's share of each retail food dollar is about 15 cents, by the Agriculture Department's measure.

Antitrust law has slowed concentration without reversing it: the US Justice Department cleared Bayer's purchase of Monsanto in 2018 only after ordering about $9 billion of sales to BASF, the largest divestiture it had ever required, and the European Commission imposed similar conditions. China's ownership of Syngenta has made seeds and chemicals, like fertilizer, a strategic question.

6e. Argued: How to Regulate Gene Editing

The case for light rules, as plant scientists and most farm groups make it, starts with the edit itself. A small change to a plant's own DNA can be identical to one that occurs naturally or that breeders have induced with radiation and chemicals since the 1950s, which no country regulates as GM. Treating it as GM adds a decade and tens of millions of dollars to each product, which only the largest firms can afford.

On this view, heavy rules protect the incumbents they claim to restrain and delay crops that need fewer chemicals or survive drought, such as mildew-resistant wheat or drought-tolerant rice.

The case for strict rules, as organic farmers, consumer groups, and several EU governments make it, rests on uncertainty and control. Edits can have unintended effects elsewhere in the genome, and without labels

and traceability, buyers and organic farmers cannot avoid them. Patents on edited traits, they add, will tighten the grip of the same few firms on seed, and herbicide-tolerant edits would deepen the dependence on chemicals that the treadmill already shows.

The evidence favors the first case on safety and the second on economics: the US National Academies found in 2016 no substantiated evidence that GM foods were less safe than conventional ones, and recommended regulating crops by their traits rather than by the method that made them. On the other hand, herbicide-tolerant crops did breed resistant weeds, and edited traits are being patented.

The EU's 2026 law splits the difference: plants with edits that could occur naturally (Category 1) are treated like conventional crops but labeled as seed, and herbicide tolerance is excluded. Other edits (Category 2) stay under GM rules, and a public database must list the patents.

The course's reading is that the EU's split points the right way, because the food-safety risk of a small edit is that of conventional breeding. The real questions, patents, concentration, and herbicide dependence, belong to competition and patent law rather than to food-safety rules that keep new varieties off the market.

Module 6 Key Points

Seeds, Chemicals, and Machines

• Hybrids and GM traits made seed a purchased input; by a 2022 count Bayer and Corteva sold about 40% of seed, four firms 62% of pesticides.

• Over 90% of US maize, soybeans, and cotton is GM; Europe grows almost none but imports about 30 million tonnes of GM feed.

• The Supreme Court ruled 7-2 for Bayer on glyphosate warnings in June 2026, after more than $10 billion of settlements.

• Corteva spun its seed business off as Vylor on October 1, 2026; Deere's sales fell about a quarter from the 2023 peak.

• A small gene edit carries conventional breeding's risks; the live questions are patents, labels, and herbicide traits, which the EU's 2026 law addresses.

Module 6 Quiz

Check Your Understanding

1. Why must farmers buy hybrid maize seed every year?

A) Seed laws forbid saving any seed from a harvest
B) Hybrids produce no seed at all
C) Hybrid vigor fades in the next generation
D) Federal law requires certified seed for every planting

2. What did the Supreme Court decide in Monsanto v. Durnell in June 2026?

A) Federal pesticide law preempts state failure-to-warn claims
B) Glyphosate causes cancer
C) Bayer must pay a $10 billion fine
D) States may require cancer warnings that federal regulators have not approved

3. What happened to Corteva on October 1, 2026?

A) It merged with BASF's farm business to form the largest seller
B) It was bought by Syngenta's Chinese owner, Sinochem
C) It sold Pioneer to Bayer after an antitrust review
D) It spun off its seed business

4. What did the US Justice Department require before clearing Bayer's purchase of Monsanto?

A) That Bayer stop selling glyphosate
B) About $9 billion of divestitures, mainly to BASF
C) A cap on seed prices
D) That the merged company license every trait to rivals at cost for ten years

5. What is the course's reading on how to regulate gene editing?

A) Regulate small edits like conventional breeding, and handle patents and herbicide traits through other law
B) Ban it, as the EU did in 2026
C) Treat every edited crop exactly like GM
D) Leave the labeling of edited seed to the companies

Module 7 — The Traders and Processors

From Elevator to Shelf, and Whether 'Greedflation' Was Real

Recommended Reading / Reference

Book: Dan Morgan, *Merchants of Grain* (1979)

Book: Jonathan Kingsman, *The New Merchants of Grain* (2019)

Report: US Federal Trade Commission, *Feeding America in a Time of Crisis* (March 2024)

Reference: CME Group agricultural futures data; USDA Economic Research Service, Food Dollar Series

7a. The Big Grain Traders

Company	Home and ownership	What it does	Note
ADM (Archer Daniels Midland)	United States; listed	Grain handling, oilseed crushing, maize processing into ethanol and sweeteners	One of the two largest crushers in the Americas
Bunge	United States, domiciled in Switzerland; listed	The largest oilseed processor; grain trading	Absorbed Viterra, Glencore's former grain arm, in July 2025
Cargill	United States; private, owned by the Cargill and MacMillan families	Grain, oilseeds, meat, feed, cocoa, salt, and financial trading	The largest private company in the United States; a record $6.7 billion profit in fiscal 2022
Louis Dreyfus Company	Netherlands; private, 45% owned since 2021 by ADQ, an Abu Dhabi state fund	Grain, oilseeds, cotton, coffee, sugar, juice	The Gulf's stake in a trader
COFCO International	China; state-owned	China's own import chain, buying in Brazil and the Black Sea	Beijing's way around the big Western traders
Wilmar	Singapore; listed	Palm oil, edible oils, Asian grain	Owns China's best-selling cooking-oil brand
Olam Agri	Singapore; 80% owned since 2026 by SALIC, the Saudi Agricultural and Livestock Investment Company	Rice, wheat milling, cotton, African trade	Saudi food security bought as a company

Four companies have moved most of the world's traded grain for a century: Archer Daniels Midland, Bunge, Cargill, and Louis Dreyfus (the ABCDs), and China's state-owned COFCO, Singapore's Wilmar, and Olam have joined them. They own the elevators, barges, export terminals, crushing plants, and ships that turn a farmer's harvest into a cargo in Rotterdam or Qingdao.

They are also processors, animal-feed makers, and, through their trading desks, among the largest hedgers in agricultural futures. Bunge's merger with Viterra, completed in July 2025, made it a rival in scale to ADM and Cargill. COFCO's rise reflects China's determination to control its own import chain, and the Gulf's stakes in Louis Dreyfus and Olam reflect the same instinct, which took Saudi Arabia's SALIC to 80% of Olam Agri in 2026.

7b. How the Trade Works, With a Hedge Worked

A farmer sells to a local elevator at the futures price minus the basis, a local discount that reflects transport and storage. The elevator hedges on the Chicago Board of Trade (CBOT), founded in 1848 and still the benchmark for maize, soybeans, and wheat, and ships to a river or rail terminal.

The exporter then loads a ship at New Orleans, Santos, or Novorossiysk for an importer, often a state buyer such as Egypt's or Algeria's, or a private miller. The sale is priced off the same futures, every link hedges, and the futures market's open interest dwarfs the physical trade.

Worked example — An Elevator's Hedge

In March, in an illustrative example, an Iowa elevator agrees to buy 50,000 bushels of maize from a farmer for delivery in October at a fixed $4.20 a bushel. It now owns maize it does not yet have and loses if the price falls, so it sells ten December CBOT maize futures contracts, each for 5,000 bushels, at $4.50. The basis, the gap between the local cash price and the futures, is minus 30 cents, typical for Iowa. By October the price has fallen: December futures are $3.90 and the local cash price is $3.60. The elevator sells the physical maize for $3.60, 60 cents below what it paid, and buys back its futures at $3.90, a gain of 60 cents. Net, it earns its handling margin and nothing else, which is the point, and had prices risen, the gain on the maize would have offset the loss on the futures. The one risk left is the basis: had the local discount widened to 40 cents, the elevator would have lost 10 cents a bushel. Multiply this across the farmers, elevators, crushers, millers, and exporters who hedge, and the futures market works as the grain trade's insurance. The argument over speculation concerns the funds that take the other side, which held a record share of open interest in 2022.

The traders' edge is information, from their own crop scouts, satellite yield estimates, and knowledge of every cargo afloat, and logistics, since they own the bottlenecks. Their profits rise with volatility: the disruption of 2022 produced record earnings across the group, including Cargill's $6.7 billion, which drew calls for windfall taxes, and the grain surplus of 2024-25 then cut their earnings sharply.

7c. Downstream: Packers, Manufacturers, and Retail

Layer	Leaders	Concentration	Note
Beef packing (US)	JBS, Tyson, Cargill, National Beef	Four firms slaughter about 85% of fed cattle	Repeated price-fixing settlements; a Justice Department investigation of beef prices opened in November 2025
Poultry (US)	Tyson, Pilgrim's Pride (JBS), Wayne-Sanderson (Cargill and Continental Grain), Perdue	Four firms about half	Price-fixing settlements in 2021-24
Pork (US)	Smithfield (owned by China's WH Group), JBS, Tyson, Hormel	Four firms about two-thirds	Smithfield listed its shares again in January 2025
Food manufacturers	Nestlé, PepsiCo, Unilever, Mondelez, Kraft Heinz, Danone, General Mills, Mars	A few firms lead most categories	They capture the largest share of the retail food dollar
Retail (US)	Walmart, Kroger, Costco, Albertsons, Aldi	Walmart alone sells about a quarter of groceries	Courts blocked the Kroger-Albertsons merger in December 2024
Retail (UK and Germany)	Tesco, Sainsbury's, Asda, Aldi, Lidl; Edeka, Rewe, Aldi, Lidl	The top four sell two-thirds to more than three-quarters	The discounters keep gaining share

Layer	Leaders	Concentration	Note
The farmer	About 1.9 million US farms	Fragmented	Keeps about 15 cents of each US food dollar

Beyond the traders the chain narrows again: four meatpackers slaughter about 85% of American fed cattle and have settled repeated price-fixing suits. Manufacturers turn commodities into brands and keep the largest share of the retail dollar, so a box of cereal holds a few cents of grain. Retail is concentrated country by country, and its buying power is the pressure that runs back down the chain to the farm.

7d. Argued: Was 'Greedflation' Real?

The case that it was, as consumer groups, some economists, and several regulators made it, starts with the timing. The FAO Food Price Index fell from its March 2022 peak of 160.2 to about 120 by mid-2023, yet American food-at-home prices, up 11.4% in 2022, rose another 5.0% in 2023. Companies told investors they were pricing ahead of costs, and margins at meatpackers and many brands widened.

Economists at the Federal Reserve Bank of Kansas City estimated that rising markups could account for more than half of American inflation in 2021. The European Central Bank found that profits drove an unusually large share of the euro area's domestic inflation in 2022. In March 2024 the FTC reported that grocery retailers' revenues had risen further above their costs than at any time in two decades.

The case that it was not, as the industry and many other economists made it, starts with costs. Energy, labor, transport, and packaging all rose sharply, and supermarkets' net margins are thin, typically 1-3% of sales, and prices lag costs on the way down as well as up, because of contracts and inventories.

Britain's Competition and Markets Authority found in 2023 that weak competition among supermarkets was not driving grocery inflation, since their profits had fallen, and higher markups in a demand surge, on this view, are simply how a market rations scarce goods.

The evidence supports a middle position: margins widened most in the middle of the chain, among processors, meatpackers, and some brands, more than at most retailers, and they narrowed again as costs eased. US food-at-home inflation was back to 2.2% a year in August 2026, though prices stayed far above their 2021 level.

The course's reading is that profits amplified the food inflation of 2021-23 rather than caused it, as sellers with pricing power, above all in concentrated links like meatpacking, used a shared shock to raise prices beyond their costs. The extra margin faded as the shock passed, and the lasting remedy is competition policy, which is slow, rather than price controls, which would cut supply.

Module 7 Key Points

The Traders and Processors

• ADM, Bunge, Cargill, and Louis Dreyfus, plus COFCO, Wilmar, and Olam, own the elevators, crushers, terminals, and ships of world grain.

• Bunge absorbed Viterra in July 2025; Abu Dhabi owns 45% of Louis Dreyfus, and Saudi Arabia's SALIC 80% of Olam Agri.

• Every link hedges on futures, so a hedged elevator earns its handling margin and carries only basis risk.

• Four packers slaughter about 85% of US fed cattle and Walmart sells a quarter of US groceries; the farmer keeps about 15 cents.

• Profits widened in 2021-23, mostly mid-chain, and amplified food inflation; they faded as costs eased, and competition policy is the remedy.

Module 7 Quiz

Check Your Understanding

1. Who are the ABCDs?

A) The four largest seed and pesticide companies
B) The four largest supermarket chains in America and Europe
C) The big state grain buyers
D) ADM, Bunge, Cargill, and Louis Dreyfus

2. In the worked example, what risk does the hedged elevator still carry?

A) A fall in the futures price before the harvest
B) A rise in the futures price after it has sold its contracts
C) A change in the basis
D) The exchange defaulting on its futures contracts

3. What did Bunge's 2025 merger with Viterra create?

A) A trader owned by Abu Dhabi
B) The first grain trader listed in New York and Shanghai
C) A rival in scale to ADM and Cargill
D) A fertilizer producer to rival the largest potash miners

4. Why does the course call profits an amplifier rather than a cause of the 2021-23 food inflation?

A) Profits fell throughout the period
B) Firms with pricing power raised prices beyond rising costs, and the extra margin faded as costs eased
C) Retail prices fell as fast as commodities
D) Supermarkets set prices for the whole chain

5. What happened to the proposed Kroger-Albertsons merger?

A) It was completed in 2024
B) It was approved with store sales
C) Walmart bought both chains after the regulators objected
D) Courts blocked it in December 2024

Module 8 — Livestock, Meat, and Dairy

The Half of Agriculture That Eats the Other Half

Recommended Reading / Reference

Paper: Joseph Poore and Thomas Nemecek, 'Reducing food's environmental impacts through producers and consumers' (*Science*, 2018)

Report: OECD-FAO, *Agricultural Outlook 2026-2035* (June 29, 2026), meat and dairy chapters

Reference: USDA Animal and Plant Health Inspection Service (APHIS) on avian influenza and screwworm; the World Organisation for Animal Health (WOAH) on swine fever

8a. The Feed Conversion

Product	Feed per kg of meat	Emissions (kg CO2e per kg)	Land (m² per kg)	World production	Largest producers
Beef (beef herds)	6-8 kg on feedlots, far more on pasture	About 100	About 330	About 77 Mt	United States, Brazil, China
Lamb and mutton	Mostly grazed	About 40	About 370	About 19 Mt	China, Australia, New Zealand
Pork	About 3	About 12	About 17	About 120-125 Mt	China (about half), EU, United States
Poultry	About 2	About 10	About 12	About 145 Mt	United States, China, Brazil
Eggs	About 2-2.5	About 5	About 6	About 95 Mt	China, India, United States
Milk (per liter)	About 1	About 3	About 9	About 950 billion liters	India, EU, United States
Farmed fish	About 1-1.5	About 14	About 8	103 Mt (all farmed aquatic animals)	China, India, Indonesia
Tofu, for comparison	—	About 3	About 2	—	China

Emissions and land are Poore and Nemecek's global averages, which vary widely by farm. CO2e, carbon dioxide equivalent, counts methane and nitrous oxide at their warming effect. Production: OECD-FAO for 2025; FAO for farmed fish (2024). A square meter (m²) is 10.8 square feet.

Livestock occupy most of the world's farmland, much of it pasture, and eat about a third of its grain and most of its soybean meal. In return, animal foods supply about a sixth of the calories people eat and about two-fifths of their protein. The arithmetic turns on the feed-conversion ratio: about 2 kilograms of feed for a kilogram of chicken, about 3 for pork, 6-8 for feedlot beef, and close to 1 for farmed fish.

Beef is therefore the most land- and emission-intensive food per calorie, and chicken the least among meats. The shift from red meat to poultry, which overtook pork as the world's most produced meat in the late 2010s, is the largest efficiency gain in the food system that nobody planned. World meat consumption is about 370 million tonnes a year, rising with incomes, above all in Asia, and China alone raises about half the world's pigs.

8b. The Industry

Meat is an industrial product: integrated companies own the genetics, feed mills, contract growers, and slaughterhouses, and Brazil's JBS is the largest, followed by Tyson, Cargill, and Smithfield, which China's WH Group owns. Brazil's Marfrig and BRF merged in 2025, and two breeding companies, Aviagen and Cobb, supply the genetics of most of the world's broiler chickens.

Dairy is led by India, the largest producer, mostly from smallholders' cows and buffalo, followed by the European Union and the United States, with New Zealand the largest exporter. China rebuilt its pig industry after swine fever partly in multi-story 'hog hotels' holding tens of thousands of animals.

American beef shows how slowly the sector adjusts: drought and high costs shrank the US cattle herd to 86.2 million head on January 1, 2026, the fewest since 1951, and rebuilding takes years because heifers kept for breeding are not sold for meat. Beef and veal prices rose 5.9% in the year to August 2026, while egg prices fell 23% as flocks recovered from avian flu.

8c. Disease

Disease	Years	Effect	Risk to people	Status in 2026
African swine fever	2018-19 in China; spreading since	Killed perhaps a quarter of the world's pigs, mostly in China; pork prices doubled there	None	Present in Europe's wild boar; Spain, the EU's largest pork exporter, found its first cases since 1994 near Barcelona in November 2025
Avian influenza (H5N1)	2021-26	Hundreds of millions of birds culled; US eggs a record $6.23 a dozen in March 2025; spread to US dairy cattle in 2024	About 70 human cases in the US, one death	About 1,170 US dairy herds infected since March 2024, including 85 in 2026 through late August
New World screwworm	2023-26	A flesh-eating fly larva that spread north through Central America and Mexico	Rare human cases	The US suspended Mexican cattle imports in 2025; Mexico resumed sales under tight controls in August 2026
Foot-and-mouth disease	Recurring	Trade bans	None	Germany's first case since 1988 in January 2025, then Hungary and Slovakia
Bovine spongiform encephalopathy (BSE), or 'mad cow' disease	1986-2000s	Britain's herd culled; global beef bans	About 230 deaths from its human form	Controlled by feed bans
Antimicrobial resistance	Ongoing	Farm animals take about 70% of antimicrobials sold, by one estimate	Rising	EU bans antibiotics as growth promoters; US limits

US human-case count from the CDC for 2024-25.

Concentrated animals mean concentrated disease: African swine fever killed perhaps a quarter of the world's pigs in 2018-19, mostly in China. Avian influenza has forced the culling of hundreds of millions of birds since 2021, drove American egg prices to a record in 2025, and jumped to dairy cattle in 2024, infecting about 1,170 herds by late August 2026. It has infected people too, mostly mildly, and it is the pandemic risk the industry most fears.

8d. Alternative Protein and the Demand Shift

The boom in plant-based meat from 2015 to 2021 faded on price, taste, and a backlash against processed food. Beyond Meat, worth more than $10 billion after its 2019 listing, has lost more than 95% of its value. Cultivated meat, grown from animal cells, is approved for sale in Singapore, the United States, Israel, and Australia but sells in tiny volumes, and Italy and at least seven American states had banned or paused its sale by late 2025.

The demand shift that did arrive came from medicine: GLP-1 weight-loss drugs reduce how much their users eat (Module 15), but meat demand as a whole keeps rising with incomes in Asia, Africa, and Latin America. The OECD-FAO Outlook projects world meat consumption up 12% to about 412 million tonnes by 2035, with poultry growing fastest, so the shift from beef toward chicken keeps making the sector more efficient without anyone deciding it should.

Module 8 Key Points

Livestock, Meat, and Dairy

• Livestock use most farmland and a third of grain; animal foods supply about a sixth of calories and two-fifths of protein.

• Beef averages about 100 kg CO2e per kilogram in Poore and Nemecek's data, poultry about 10, and tofu about 3.

• The US cattle herd fell to 86.2 million on January 1, 2026, the fewest since 1951; beef prices rose 5.9% in a year.

• H5N1 has infected about 1,170 US dairy herds since 2024; screwworm closed the border to Mexican cattle until August 2026.

• Plant-based meat faded; OECD-FAO projects meat consumption up 12% to about 412 Mt by 2035, led by poultry.

Module 8 Quiz

Check Your Understanding

1. Which meat has the largest emissions per kilogram in Poore and Nemecek's averages?

A) Beef
B) Chicken raised indoors
C) Pork from Chinese hog hotels
D) Farmed salmon fed on fish oil

2. Why did the United States stop importing Mexican cattle in 2025?

A) New World screwworm, a flesh-eating parasite, spread north through Mexico toward the border
B) A tariff dispute
C) Foot-and-mouth disease
D) Mexico banned exports to protect its herd

3. How many US dairy herds had H5N1 infected since March 2024, by late August 2026?

A) Fewer than 50, all in Texas
B) About 20
C) About 1,170
D) More than 10,000, a third of all herds

4. What does the OECD-FAO Outlook project for world meat consumption by 2035?

A) A fall as plant-based meat takes a fifth of the market
B) Up 12%
C) Flat, as rich countries eat less and poor countries cannot afford more
D) A doubling, led by beef in Africa

5. Where did the US cattle herd stand in 2026?

A) A record high
B) Growing fast on cheap feed
C) Down by half since the screwworm outbreak began in 2024, by USDA's count
D) The smallest since 1951, at 86.2 million head

Module 9 — Fish and Aquaculture

The Ocean and the Fish Farm

Recommended Reading / Reference

Report: FAO, *The State of World Fisheries and Aquaculture 2026* (SOFIA), June 2026

Paper: U. Rashid Sumaila and colleagues, 'Updated estimates and analysis of global fisheries subsidies' (*Marine Policy*, 2019)

Reference: Global Fishing Watch, satellite tracking of fishing vessels; company reports from Mowi and Thai Union

9a. Wild Catch and Farmed

Source	Production (2024)	Trend	Leaders	Note
Wild capture, marine	80 Mt	Flat since the 1990s	China, Indonesia, Peru, Russia, the US, India	About a third of assessed stocks overfished
Wild capture, inland	12 Mt	Flat to falling	China, India, Bangladesh, Burma	Protein for the poor of Asia and Africa
Aquaculture, aquatic animals	103 Mt	Above 100 Mt for the first time; 53% of the total	China, India, Indonesia, Vietnam, Bangladesh, Norway, Chile, Egypt	Farm-gate value $371 billion
Aquaculture, algae	About 38 Mt	Growing	China, Indonesia, South Korea	Food, thickeners, feed
All aquatic animals	195 Mt	A record		21.3 kg eaten per person a year, about twice the 1960s level
All production, including algae	235 Mt	A record		Trade in aquatic animal products a record $184 billion

FAO, SOFIA 2026. Weights are live weight. A kilogram is 2.2 pounds.

Fish is the quiet revolution in the food system: wild marine catch reached about 80 million tonnes in the 1990s and has not grown since, because the ocean has no more to give. By the FAO's 2025 review, about 35% of assessed stocks are overfished, and most of the rest are fished to their limit, though SOFIA 2026 found that 72.6% of 2023 landings came from biologically sustainable stocks.

The North Atlantic's cod fisheries collapsed in the early 1990s, and bluefin tuna was fished down to a fraction of its stock before quotas brought it back. Governments subsidize their fleets by about $35 billion a year, about $22 billion of it in forms that expand fishing capacity, by Sumaila and colleagues' estimate. A World Trade Organization (WTO) agreement curbing some of those subsidies, agreed in 2022, took effect in September 2025.

Aquaculture filled the gap, producing 103 million tonnes of fish, shellfish, and other aquatic animals in 2024, 53% of the total, and China produces more than half of the farmed supply. Farmed fish have the best feed conversion of any animal, close to one kilogram of feed per kilogram of fish, which makes them the most efficient source of animal protein, while their problems are livestock's problems at sea.

9b. The Species and the Industry

Species	Farmed production	Leading producers	Market	Issues
Carps	About 30 Mt	China, India, Bangladesh	Domestic staples in Asia	Low input; pond culture
Tilapia	About 7 Mt	China, Indonesia, Egypt, Brazil	Cheap white fish	Freshwater; efficient
Shrimp	About 7-9 Mt	Ecuador, India, Vietnam, Indonesia, China	The most valuable traded seafood	Disease, lost mangroves, antibiotics, and labor abuses
Atlantic salmon	About 3 Mt	Norway (about half), Chile, the UK, the Faroes, Canada	Premium	Sea lice, escapes, and disease; Norway taxes its profits at 25% since 2023
Pangasius catfish	About 3 Mt	Vietnam	Cheap white fish for export	The Mekong delta
Oysters, mussels, clams	About 18 Mt	China, Chile, Spain, France	Filter feeders that need no feed	The most sustainable animal protein
Wild anchoveta, pollock, tuna, mackerel	About 25 Mt (largest species)	Peru, Russia, the US, Japan, Indonesia	Fishmeal and fish oil, fillets, canned tuna	Quotas and treaties; tuna stocks recovering

Rounded FAO figures for 2022-24.

9c. The Feed Problem, El Niño, and Illegal Fishing

Farmed carnivores such as salmon and shrimp historically ate wild fish as fishmeal and fish oil, so a kilogram of farmed salmon once consumed several kilograms of anchovies and sardines. The industry has cut that ratio below one by switching to soy, insect meal, algae oil, and single-cell proteins.

Even so, the anchoveta fishery off Peru, the world's largest by volume, still supplies much of the fish oil in salmon feed, and El Niño years that warm its waters cut the catch and move feed prices worldwide. Peru cancelled its first anchovy season of 2023 during the last El Niño, and a strong El Niño, forecast for the winter of 2026-27, threatens it again (Module 11).

Illegal, unreported, and unregulated fishing takes an estimated 11-26 million tonnes a year, worth $10-23 billion, much of it by distant-water fleets, China's above all, which is the world's largest and is documented by satellite off West Africa, the Galápagos, and Argentina. Global Fishing Watch's tracking has made the problem visible, but enforcement still depends on coastal states with few patrol boats.

Module 9 Key Points

Fish and Aquaculture

• Aquaculture produced 103 Mt of aquatic animals in 2024, 53% of the total and over 100 Mt for the first time.

• Wild marine catch has been flat at about 80 Mt since the 1990s, and about a third of assessed stocks are overfished.

• Farmed fish convert feed almost one to one, the best of any animal, but farmed salmon still need some fish oil.

• A WTO agreement curbing harmful fishing subsidies, about $22 billion a year, took effect in September 2025.

• Illegal fishing takes an estimated 11-26 Mt a year; satellite tracking has made it visible, and enforcement lags.

Module 9 Quiz

Check Your Understanding

1. What milestone did farmed aquatic animals pass in 2024, by the FAO's 2026 report?

A) Half of all seaweed
B) The output of beef
C) A tenth of world seafood
D) More than 100 million tonnes for the first time, 53% of aquatic animal output

2. What share of 2023 landings came from biologically sustainable stocks, by SOFIA 2026?

A) About 73%
B) Half
C) A fifth
D) Under a third, because most stocks have collapsed

3. When did the WTO agreement curbing harmful fishing subsidies take effect?

A) In 2022, the day it was signed
B) In 2001
C) September 2025
D) It has not, because India blocked it at the 2024 ministerial

4. Why does a strong El Niño matter to salmon farmers?

A) It warms Norwegian fjords enough to kill most salmon each summer
B) It cuts Peru's anchovy catch
C) It raises the price of soy-based feed through drought in Brazil
D) It closes the Panama Canal to salmon exports

5. How large is illegal, unreported, and unregulated fishing, by the usual estimate?

A) Under 1% of the catch
B) About half the catch
C) About 11-26 million tonnes a year
D) It cannot be estimated because satellites cannot see fishing boats at night

Module 10 — Land, Soil, and the Environment

What Farming Does to the Planet, and the Dutch Nitrogen Fight

Recommended Reading / Reference

Report: FAO, *Greenhouse Gas Emissions From Agrifood Systems: Global, Regional and Country Trends, 2001-2023* (October 2025)

Report: World Resources Institute (WRI) and the University of Maryland, Global Forest Watch tree-cover-loss data for 2025 (April 29, 2026)

Reference: Elizabeth Goldman and colleagues, *Estimating the Role of Seven Commodities in Agriculture-Linked Deforestation* (WRI, 2020); the texts of the EU Deforestation Regulation and its 2025 amendment; rulings of the Dutch Council of State (2019) and the Hague District Court (2025)

10a. Deforestation

Commodity	Forest replaced, 2001-2015	Where	Rules aimed at it
Cattle pasture	45.1 million ha	The Brazilian Amazon and Cerrado, Paraguay, Bolivia, Colombia	Brazil's Forest Code; the EU Deforestation Regulation (EUDR)
Oil palm	10.5 million ha	Indonesia and Malaysia	Indonesia's permanent moratorium on clearing primary forest and peat; the EUDR
Soybeans	8.2 million ha	The Cerrado, the Amazon's edges, the Gran Chaco	The Amazon Soy Moratorium, which the big traders began leaving in January 2026; the EUDR
Cocoa	2.3 million ha	Côte d'Ivoire and Ghana	Company pledges; the EUDR
Rubber, coffee, and plantation wood	5.6 million ha	Southeast Asia, Latin America, Africa	The EUDR
The seven together	About 72 million ha, twice the area of Germany	Mostly the tropics	About 57% of agriculture-linked tree-cover loss

WRI (Goldman and colleagues, 2020). A hectare (ha) is 2.47 acres.

Agriculture drives about 90% of tropical deforestation, directly or indirectly, and four commodities account for most of it: cattle, oil palm, soybeans, and cocoa. Pasture for cattle replaced more forest than the other six commodities combined in 2001-2015, mostly in the Amazon, while soybeans expanded across the Cerrado and the Chaco, palm oil across Sumatra and Borneo, and cocoa across West Africa, where Côte d'Ivoire has lost most of its forest.

The loss slowed in 2025: Global Forest Watch measured 4.3 million hectares of tropical primary forest lost that year, 36% less than in the record year of 2024, and Brazil's loss not caused by fire fell to the lowest on record. Fire is the new threat: 42% of the world's tree-cover loss in 2025 was fire-related, and Bolivia ranked second only to Brazil for primary forest lost.

Brazil's own satellite system, run by its space research institute (INPE), measured 5,796 square kilometers (2,238 square miles) of Amazon clearing in the year to July 2025, down 11%, but the rules are moving the other way. After a Mato Grosso law ended tax benefits for companies in the Amazon Soy Moratorium on

January 1, 2026, Abiove, the association of Brazil's oilseed crushers and grain traders, and many of its members, including ADM, Bunge, Cargill, COFCO, and Louis Dreyfus, began leaving the 2006 pact.

The EUDR bars imports of cattle, soy, palm oil, cocoa, coffee, rubber, and wood grown on land deforested after 2020. It has been delayed twice, most recently to December 30, 2026 for large companies and June 30, 2027 for small ones, and a Commission review in May 2026 left its core text in place but proposed dropping leather.

10b. Emissions

Source	Emissions (Gt CO2e, 2023)	Share of the agrifood total	Note
On the farm: crops and livestock	8.1	49%	Livestock 4.3 Gt, the largest single component: cattle's methane and manure; also rice paddies' methane and fertilizer's nitrous oxide
Land-use change	3.2	19%	Deforestation 2.8 Gt; down 6% since 2001
Before and after the farm	5.2	32%	Fertilizer manufacture, processing, packaging, transport and retail (1.4 Gt), cooking, and waste; up 33% since 2001
All agrifood systems	16.5	100%	32% of all human-caused emissions, down from 38% in 2001

FAO (October 29, 2025). Gt is billion tonnes; CO2e is carbon dioxide equivalent.

The food system produced about 16.5 billion tonnes of greenhouse gases in 2023 by the FAO's count, 32% of the human total, and half came from the farm itself, as methane from cattle and rice paddies and nitrous oxide from fertilizer. Counting their feed and the land cleared for them, livestock account for about 12% of all human emissions, by an earlier FAO estimate.

Climate policy has moved more slowly in food than in energy because it collides with food prices, farm politics, and diets. The European farmer protests of 2024, the American farm lobby's weight in every climate bill, and the Dutch nitrogen fight are the measure of the resistance.

10c. Soil and Biodiversity

The FAO judged in 2015 that about a third of the world's soils were moderately to highly degraded, by erosion, compaction, salt, or loss of organic matter. The UN's desertification convention estimates that about 24 billion tonnes of fertile soil are lost each year, far faster than soil forms, and fertilizer masks the decline in yields until it cannot.

The responses are spreading: no-till farming, which leaves the soil undisturbed, covered about 200 million hectares by 2018-19, mostly in the Americas, and cover crops and rotations are growing. Companies now pay farmers to store carbon in soil, though how much carbon is stored, and for how long, remains hard to measure.

Farming is also the largest cause of biodiversity loss, through habitat conversion, pesticides, and fertilizer runoff, and flying-insect biomass fell by more than 75% over 27 years in German nature reserves. Nutrient runoff creates a dead zone in the northern Gulf of Mexico each summer, and three-quarters of crop types benefit from animal pollinators, whose numbers are falling.

10d. The Regulation Fights and the Dutch Case

Every attempt to regulate farming's footprint has met the same politics: after the 2024 farmer protests the European Commission withdrew its plan to halve pesticide use, loosened the green conditions on farm subsidies, and saw its Nature Restoration Law pass only in diluted form. In the United States, the farm bill's conservation programs are traded against crop subsidies in every negotiation.

The Netherlands is the clearest case, because it keeps about 100 million farm animals in a country of 18 million people, one of the densest livestock sectors in the world, and their ammonia settles as nitrogen on protected habitats. In May 2019 the Council of State, the highest administrative court, struck down the permit system that had let farms and builders expand, freezing thousands of projects.

The government proposed deep cuts near protected areas, a fund of about €25 billion, and the buyout of farms, and farmers answered with tractor blockades in 2019 and 2022. The new Farmer-Citizen Movement (BBB) became the largest party in all twelve provinces in March 2023, but when the coalition fell that July, it fell over asylum policy, not nitrogen.

Later governments slowed the cuts and offered voluntary buyouts, which drew hundreds of farmers, until in January 2025 a court in The Hague, hearing a case brought by Greenpeace, ordered the state to meet its 2030 target for protecting nitrogen-sensitive nature under threat of fines.

The case showed that environmental limits on farming can be enforced through the courts and that enforcing them is politically explosive, and it became a template for the farmer protests across Europe in 2024.

Module 10 Key Points

Land, Soil, and the Environment

• Agriculture drives about 90% of tropical deforestation; cattle replaced 45 million hectares of forest in 2001-2015, more than any other commodity.

• Tropical primary forest loss fell 36% to 4.3 million hectares in 2025, but 42% of world tree-cover loss was fire-related.

• Agrifood systems emitted 16.5 Gt CO2e in 2023, 32% of the human total, and about half came from the farm itself.

• About a third of soils are degraded, while no-till covers about 200 million hectares and three-quarters of crop types benefit from pollinators.

• The Dutch nitrogen fight, from a 2019 ruling to a 2025 court order, shows farm pollution limits are enforceable and explosive.

• Brazil's big traders began leaving the Amazon Soy Moratorium in January 2026; the EU's deforestation rules apply from December 30, 2026.

Module 10 Quiz

Check Your Understanding

1. Which commodity replaced the most tropical forest in 2001-2015, by WRI's count?

A) Cattle
B) Oil palm in Indonesia
C) Cocoa in West Africa
D) Soybeans in the Brazilian Cerrado

2. How large were agrifood systems' emissions in 2023, by the FAO's count?

A) About 2 Gt, 4% of the total
B) About 40 Gt, most of the total
C) About 9 Gt, all from livestock
D) About 16.5 Gt CO2e, 32% of human-caused emissions, about half of it on the farm

3. What happened to tropical primary forest loss in 2025?

A) It reached a new record
B) It fell by 36%
C) It doubled
D) It fell to zero in Brazil after the soy moratorium ended

4. What set off the Dutch nitrogen crisis in 2019?

A) A court ruling that the permit system for nitrogen pollution broke the law protecting habitats, freezing building and farm permits
B) A fertilizer shortage
C) A drought in the polders
D) An EU ban on Dutch milk exports

5. What brought down the Dutch coalition in July 2023?

A) Its nitrogen plan for livestock farms
B) Asylum policy
C) A farmers' strike that closed the ports
D) A court ruling against its nitrogen permits

Module 11 — Climate and the Harvest

How Warming Is Changing Yields, and the El Niño of 2026-27

Recommended Reading / Reference

Paper: Chuang Zhao and colleagues, 'Temperature increase reduces global yields of major crops in four independent estimates' (*PNAS*, 2017)

Report: Intergovernmental Panel on Climate Change (IPCC), *Sixth Assessment Report*, Working Group II, chapter 5 (food)

Reference: US National Oceanic and Atmospheric Administration (NOAA), Climate Prediction Center, El Niño-Southern Oscillation (ENSO) diagnostic discussion (monthly; October 8, 2026); India Meteorological Department monsoon statistics; Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES), *Australian Crop Report* (September 2026)

11a. Heat and the Big Crops

Crop	Heat that harms it	Yield loss per 1°C of warming, before adaptation	Most exposed regions	Recent episodes
Wheat	About 30-32°C at flowering	About 6%	India, Pakistan, Australia, southern Europe, the US Plains	India's March 2022 heat wave cut its harvest and led to an export ban
Maize	About 35°C at silking	About 7%	The US Corn Belt, Brazil, Sub-Saharan Africa, southern Europe	The 2012 US drought cut yields about a quarter below trend; the EU crop was cut in 2026
Rice	About 35°C; hot nights hurt	About 3%	South and Southeast Asia, China	India's 2026 monsoon ended 12.6% below normal
Soybeans	About 35°C	About 3%	Brazil, Argentina, the United States	Argentina's 2023 drought nearly halved its crop
Arabica coffee	Best at about 18-21°C	Suitable land could halve by 2050 if emissions stay high	Brazil, Colombia, Ethiopia, Central America	Record prices in 2025 after drought in Brazil
Cocoa	Stressed above about 32°C	West Africa's suitable belt is shrinking	Côte d'Ivoire, Ghana	The 2024 price spike

Yield losses from Zhao and colleagues (2017), which combine four methods; °C is degrees Celsius, and 1°C of warming is 1.8°F.

Each staple crop has a temperature above which yields fall steeply, and warming pushes more growing seasons past it. Combining four methods, Zhao and colleagues estimated that each degree Celsius of global warming cuts world yields by about 6% for wheat, 7% for maize, and 3% for rice and soybeans, before farmers adapt.

The losses concentrate in the tropics and subtropics, where most poor farmers live, while cooler regions gain for a while from longer seasons and more carbon dioxide, though more carbon dioxide also lowers the protein and micronutrient content of grain. Heat also shifts the calendar, with earlier springs, late frosts, and flowering that misses the rains.

11b. The 2026 Season and El Niño

The 2026 season showed how unevenly weather falls: Europe's summer drought cut the European Union's maize crop to 48 million tonnes by USDA's October estimate, and the Rhine at the Kaub gauge fell to 4 centimeters on September 24, the lowest since records began in 1880. India's monsoon ended 12.6% below its long-term average, the weakest in more than a decade, and 28% short in the south.

Australia's agricultural bureau, ABARES, forecast a winter crop of 60.9 million tonnes on September 1, down 12% from the year before, while the American Midwest grew a large maize crop and a record soybean crop.

The larger risk is still coming: on October 8, 2026 NOAA's Climate Prediction Center said an El Niño was intensifying and that a strong-to-very-strong event was likely through January-March 2027, with more than an 83% chance. The key ocean temperature index stood 2.1°C above normal, and the agency said a historic event was possible.

El Niño, a periodic warming of the eastern tropical Pacific, tends to bring drought to India, Indonesia, Australia, and southern Africa and heavy rain to parts of South America. The 2015-16 and 2023-24 El Niños cut southern Africa's maize harvests, and in 2024 Zambia, Zimbabwe, and Malawi declared national disasters.

This time South Africa harvested a record maize crop in 2026, so the region enters the season with full silos, but its planting begins in November under El Niño's shadow. A strong event also cuts palm oil yields in Indonesia and Malaysia about a year later and threatens Peru's anchovy catch, and it arrives on top of the fertilizer shock (Module 5).

11c. Water, Pests, and the Shifting Map

Irrigated land, about a fifth of cropland, grows about 40% of the world's food, and it depends on sources that warming is shrinking. The Himalayan glaciers feed the rivers behind Punjab's wheat, the Sierra Nevada's snowpack feeds California's fruit and nuts, and aquifers under India, northern China, and the Great Plains are falling. On the Colorado, the Interior Department imposed cuts for 2027-28 on August 21, 2026, after the seven states failed to agree.

Warming also moves pests and diseases toward the poles and lengthens their seasons, as locust swarms ravaged East Africa in 2019-21, and the fall armyworm has spread across Africa and Asia since 2016.

The map of what grows where is shifting: wine is moving north into England and Scandinavia, maize into Canada's prairies and northern Russia, and coffee and cocoa face shrinking suitable land, so the gainers are mostly cold, rich countries and the losers mostly hot, poor ones.

11d. Adaptation

The tools are known: breeders are developing heat- and drought-tolerant varieties, including gene-edited ones, and drought-tolerant maize is already grown on millions of African hectares. Farmers can shift planting dates and crops, expand irrigation where water allows and switch to drip where it does not, and buy insurance tied to better forecasts.

Research suggests adaptation can offset a substantial share of projected losses this century, and the losses it cannot offset fall on the countries least able to adapt. Climate is not the largest threat to food supply in the 2020s, since war, fertilizer, and policy have done more damage, but it is the one that compounds every other.

Module 11 Key Points

Climate and the Harvest

• Each degree of warming cuts yields about 6% for wheat, 7% for maize, and 3% for rice and soybeans before adaptation.

• In 2026 the Rhine hit a record low, India's monsoon ended 12.6% short, and Australia's winter crop forecast fell 12%.

• NOAA expects a strong-to-very-strong El Niño through early 2027, threatening India, Australia, Indonesia, and southern Africa.

• Irrigated land, a fifth of cropland, grows about 40% of food, fed by glaciers, snowpack, and aquifers that are shrinking.

• Adaptation can offset much of the loss; what remains falls on hot, poor countries, and climate compounds every other shock.

Module 11 Quiz

Check Your Understanding

1. How much does each degree of warming cut wheat yields before adaptation, by Zhao and colleagues' estimate?

A) About 1%
B) About 50%
C) About 6%, with maize about 7%
D) Yields rise with warming because of extra carbon dioxide

2. How did India's 2026 monsoon end?

A) At a record high, flooding the rice belt
B) Normal
C) Above normal in the south, below in the north
D) 12.6% below normal

3. What did NOAA's Climate Prediction Center say on October 8, 2026?

A) La Niña conditions have set in for the winter
B) Neutral
C) A weak El Niño is likely to end by December
D) A strong El Niño is likely

4. Why is southern Africa better placed for this El Niño than in 2024?

A) It has irrigated all its maize
B) El Niño brings it rain
C) South Africa's record 2026 maize crop left silos full
D) Donors have pre-funded food aid for the whole region through a new UN appeal

5. How does the module rank climate among threats to food supply in the 2020s?

A) Not the largest, behind war, fertilizer, and policy, but the one that compounds every other
B) The only threat that matters
C) Already solved by adaptation
D) Irrelevant to supply until 2050

Module 12 — Prices, Subsidies, and Stockpiles

The Price Record, the Policy Machinery, and the Argument Over Biofuel Mandates

Recommended Reading / Reference

Report: OECD, *Agricultural Policy Monitoring and Evaluation 2025* (October 2025)

Report: USDA Economic Research Service, farm income forecast (September 3, 2026)

Paper: Tyler Lark and colleagues, 'Environmental outcomes of the US Renewable Fuel Standard' (*PNAS*, 2022)

Reference: FAO Food Price Index (monthly; October 2, 2026); EPA, Renewable Fuel Standard volumes for 2026 and 2027 (final rule, March 2026); farmdoc daily (University of Illinois) on the final rule

12a. The Index

When	FAO Food Price Index	Context
2007-08	A first peak	Biofuel mandates, oil, thin stocks, and rice export bans
February 2011	A record at the time	Russia's 2010 export ban; the Arab Spring
March 2022	160.2, the all-time high	Russia's invasion of Ukraine
2024 average	122.0	Grain surplus; cocoa and vegetable oils up
2025 average	127.2, up 4.3%	Vegetable oils up 17.1% and dairy up 13.2%; cereals down 4.9% and sugar down 17%
December 2025	124.3	A fourth monthly fall
September 2026	136.0, up 5.8% in a year and the highest since November 2022	Cereals 122.8 (up 5.1% in the month), vegetable oils 198.6, meat 127.9, dairy 119.1, sugar 114.0

FAO, monthly releases (the index is set at 100 for 2014-16; the next release is due on November 6, 2026). The index tracks international prices of cereals, vegetable oils, meat, dairy, and sugar, not shop prices.

The FAO Food Price Index, the benchmark for world food commodity prices, reached a record in 2011, an all-time high of 160.2 in March 2022, and then eased to an average of 122.0 in 2024. In 2026 it climbed again, to 136.0 in September, its highest since November 2022 and 15% below the 2022 peak.

The composition matters as much as the headline: in September 2026 cereals rose 5.1% in a month, with wheat up 6.3% and maize up 5.6%, and sugar rose 6.1%, while vegetable oils stayed high. Shop prices move more slowly and less: American food prices were 2.7% higher in August 2026 than a year earlier, and food eaten at home only 2.2% higher.

12b. Subsidies

Country or bloc	Support	Main forms	Note
European Union	The Common Agricultural Policy (CAP): €387 billion for 2021-27, about €55 billion a year and a third of the EU budget	Payments per hectare, rural development, market measures	The 2024 protests loosened its green conditions; the Commission proposed folding it into national plans after 2027
United States	Direct government payments forecast at $47.4 billion in 2026, up nearly 70% from 2025	Crop insurance subsidies, price and revenue programs, ad hoc trade and disaster aid	The 2025 tax-and-spending law raised support prices and secured the main programs through 2031; the rest of the 2018 farm bill lapsed on September 30, 2026
China	The largest in absolute terms	Minimum purchase prices for wheat and rice, input subsidies, state stockpiles, a 'red line' of about 120 million hectares of farmland	Food security as regime security
India	Fertilizer subsidies of about $20 billion a year; free grain for 813 million people	Minimum support prices, free electricity for pumps, state procurement	Farmers forced the repeal of three reform laws in 2021
Japan, South Korea, Switzerland, Norway	Among the highest per farmer	Tariffs (Japan charges 341 yen a kilogram on rice above its quota) and direct payments	The most protected farmers
Brazil, Australia, New Zealand	Low	Credit and insurance; New Zealand abolished most subsidies in 1984	The efficient exporters
Argentina	Negative	Export taxes on farm goods, cut since 2025	Taxes its farmers rather than subsidizing them

OECD (October 2025): support across the 54 countries it monitors stayed well above pre-pandemic levels in 2022-24. US figures: USDA, September 3, 2026.

Rich and middle-income countries transfer hundreds of billions of dollars a year to their farmers, and the OECD found that support across the 54 countries it monitors stayed well above pre-pandemic levels in 2022-24. Subsidies raise output, depress world prices, entrench the crops they favor, and are almost impossible to remove, and New Zealand's abolition of most of its farm subsidies in 1984 is the one clean example.

American support has swollen with the trade war, and USDA's September 2026 forecast puts direct government payments at $47.4 billion for the year, up nearly 70%, while net farm income slips 2.6% to $158.4 billion as costs rise. The 2025 tax-and-spending law raised the reference prices behind the main crop programs and extended them through 2031, but the rest of the 2018 farm bill lapsed on September 30, 2026, leaving conservation enrollment and some dairy programs in limbo.

12c. Biofuels and Stockpiles

Biofuel mandates tie food to fuel: in the United States the Renewable Fuel Standard (RFS) sends about a third of the maize crop to ethanol and, through biodiesel and renewable diesel, about half of soybean oil. Brazil turns about half its sugarcane into ethanol and raised the ethanol blend in gasoline to 30% in August 2025, India reached a 20% blend in 2025, and Indonesia burns palm oil in diesel.

The EPA's final rule of March 2026 set record volumes: 26.81 billion Renewable Identification Numbers (RINs), the credits that track compliance, for 2026 and 27.02 billion for 2027. Biomass-based diesel gets 9.07 billion RINs in 2026, roughly 5.7 billion physical gallons, and imported fuels and feedstocks are to earn only half credit from 2028.

Stockpiles are the other lever, and by USDA's 2026/27 projections China holds about three-fifths of the world's maize stocks, more than half of its rice, and about 44% of its wheat, and it does not sell them abroad. India's state stocks back its free-grain program, and Japan released reserve rice in 2025 when prices doubled. Most rich countries hold only private, commercial stocks, which is one reason the market reacts so sharply to a poor harvest.

12d. Argued: Biofuel Mandates

The case for the mandates, as farm groups, the ethanol and biodiesel industries, and farm-state politicians make it, starts with income and security. A guaranteed market for a third of the American maize crop and half its soybean oil props up farm prices without a direct subsidy check.

Supporters add that fuel made at home cushions an oil shock like 2026's, that Argonne National Laboratory's models show corn ethanol emitting 40-50% less than gasoline over its life, and that a third of the maize returns to the feed market as distillers' grains.

The case against, as food-security groups, many economists, and environmental scientists make it, starts with competition for land and calories. Mandates lock in demand regardless of harvests, tie food prices to oil, and helped cause the 2008 crisis.

Critics also cite Lark and colleagues, who estimated in 2022 that once land converted to maize is counted, American corn ethanol is likely no better for the climate than gasoline and possibly worse. Fixed mandates, they add, are least defensible in a shortage, when the grain is most needed as food.

The evidence supports parts of both: estimates of biofuels' share in the 2008 price spike ranged from a few percent in a USDA analysis to about three-quarters in a World Bank paper, depending on the model, and the effect is larger when stocks are thin. The climate result turns on how land-use change is counted, which is why estimates differ so widely, while the farm-income benefit is real and concentrated in a few states.

The course's reading is that mandates should work as a flexible buffer rather than a rigid floor. They should be waived automatically when food prices spike, crop-based fuels should be capped, as the European Union caps them at 7% of transport energy, and credit should favor wastes and residues over food crops.

12e. The Politics of Food Inflation

Food takes 10-15% of household spending in rich countries and 40-60% in poor ones, which makes food inflation the most politically dangerous kind. The 2010-11 episode is the template: a summer export ban was shrugged off for months, and governments were falling in North Africa by the following winter. The countries most exposed to a 2026-27 rerun are import-dependent, short of foreign currency, and already hungry, such as Egypt, Pakistan, Bangladesh, Nigeria, and the Sahel states.

Module 12 Key Points

Prices, Subsidies, and Stockpiles

• The FAO Food Price Index reached 136.0 in September 2026, up 5.8% in a year and the highest since November 2022.

• Its all-time high was 160.2 in March 2022; the 2025 average was 127.2, with oils up 17% and cereals down 5%.

• US direct farm payments are forecast at $47.4 billion in 2026, up nearly 70%, while net farm income slips 2.6%.

• The EPA's final rule set record volumes, 26.81 billion RINs for 2026; ethanol takes about a third of US maize.

• China holds about three-fifths of world maize stocks, over half of rice, and 44% of wheat, outside the world market.

• The course's reading: biofuel mandates should flex, waived in price spikes and capped for crop-based fuels.

Module 12 Quiz

Check Your Understanding

1. Where did the FAO Food Price Index stand in September 2026?

A) At an all-time high, above its 2022 peak
B) At 136.0
C) Unchanged from a year earlier, at about 128
D) At its lowest since 2020, after record harvests

2. How much did USDA expect to pay American farmers directly in 2026, by its September forecast?

A) About $5 billion
B) About $12 billion, all in aid for soybeans
C) About $47.4 billion, up nearly 70% from 2025 and more than a quarter of net farm income
D) About $200 billion, more than net farm income

3. What did New Zealand do in 1984?

A) Abolished farm subsidies
B) Banned GM crops and imports of GM feed
C) Became the largest dairy exporter by subsidizing exports
D) Joined the EU's farm policy as an associate

4. What is the course's reading on biofuel mandates?

A) Abolish them
B) Raise them, since 2026 proved their value
C) Keep them fixed, because flexibility would destroy investment in biorefineries and rural jobs
D) Keep them flexible: waived in price spikes, with crop-based fuels capped

5. Who holds most of the world's maize and rice stocks?

A) The United States, in its strategic reserve
B) China, by far
C) India
D) The UN's World Food Programme, for emergencies

Module 13 — Trade Policy and Export Bans

The Rules and the Weapons of Food Trade, and India's Rice Bans

Recommended Reading / Reference

Reference: International Food Policy Research Institute (IFPRI), Food and Fertilizer Export Restrictions Tracker; WTO agriculture negotiations; USDA Foreign Agricultural Service export sales data; Directorate General of Foreign Trade (DGFT), India, export notifications; *Learning Resources, Inc. v. Trump* (US Supreme Court, February 20, 2026)

13a. Tariffs, Quotas, and the WTO

Agriculture is the least liberalized part of world trade, and it entered the WTO's rules only with the Uruguay Round of 1994, which converted quotas into tariffs and capped subsidies. The Doha Round that was meant to go further collapsed in 2008 over exactly these questions, above all a safeguard that India and China wanted for raising tariffs when imports surged, along with America's cotton subsidies and Europe's farm support.

The result is a system of high tariffs on sensitive goods, such as Japan's on rice, the EU's on sugar and beef, and Canada's on dairy, and of tariff-rate quotas that admit fixed volumes at low duty, while health and plant-safety rules, known as sanitary and phytosanitary measures, often work as barriers too. The WTO's appeals body has been unable to rule since December 2019, when the United States blocked the appointment of new judges.

The American tariffs of 2025 reopened questions the WTO had settled. On February 20, 2026 the Supreme Court ruled 6-3 that the International Emergency Economic Powers Act (IEEPA), the law used for most of them, does not authorize tariffs, and the administration turned to other trade laws, including a temporary global tariff and new investigations of major trading partners.

13b. Export Bans

Years	Country	Goods	Measure	Effect	Status in October 2026
2007-08	India, Vietnam, Egypt, and others	Rice	Bans and floor prices	Thai rice nearly tripled	Lifted
2010-11	Russia	Wheat and other grains	Ban after drought and fires	Wheat up by more than half	Lifted in 2011
2022	Indonesia	Palm oil	Ban of about three weeks	Vegetable oils to records	Reversed under domestic pressure
2022-26	India	Wheat	Ban after the March 2022 heat wave	Chicago wheat rose about 6% the next trading day	Lifted August 24, 2026, after a record harvest
2022-24	India	Rice	Bans, duties, and floor prices	Prices highest since 2008; about 40% of world trade affected	Lifted in 2024-25
2021-26	China	Urea and phosphate	Export inspections, quotas, and licenses	Higher prices for importers	Urea limits relaxed in mid-2026
2022-26	Russia	Fertilizer and wheat	Quotas and floating export taxes	Prices kept firm	Used as a policy lever

Years	Country	Goods	Measure	Effect	Status in October 2026
2026	Gulf producers (by war, not law)	Urea, ammonia, sulfur	The Hormuz closure	Urea exports from Hormuz-dependent states down 83% in April	The strait still closed in October

IFPRI counted more than thirty countries restricting food or fertilizer exports in 2022.

Export bans are a poor country's first resort and the market's worst amplifier: each protects domestic prices by exporting the shortage to everyone else, and because exporters of the same crop react to each other, one ban breeds the next.

The 2008 rice crisis was almost entirely a policy cascade: India's restrictions prompted Vietnam's, which prompted panic buying in the Philippines, which nearly tripled the price of a crop whose harvest had not failed, and because the WTO has no enforceable discipline on export restrictions, they recur.

13c. India's Rice Bans, 2022-24

India supplies about 40% of the world's rice exports, so its domestic politics set the price for much of Asia and Africa. In September 2022, after a weak monsoon, it banned exports of broken rice and put a 20% duty on some other grades. In July 2023, ahead of national elections and with food inflation rising, it banned exports of non-basmati white rice, and it later added a duty on parboiled rice and a floor price on basmati.

The world market had nowhere else to go: importers from the Philippines to West Africa scrambled, Thai and Vietnamese prices rose in sympathy, and the FAO's rice price index reached its highest level since 2008 in August 2023, so Indian consumers were protected while poorer importers in Africa and Asia paid more.

India lifted the ban on white rice in September 2024 with a floor price, dropped the floor in October, and allowed broken-rice exports again in March 2025. With huge state stocks, India is projected by USDA to export a record 25 million tonnes in 2026/27. The lesson is that the thinnest of the grain markets depends on one exporter's domestic politics, which can turn a local inflation scare into a global price shock.

13d. The US-China Soybean War

The largest bilateral food trade on earth, American soybeans for Chinese pigs, has twice been used as a weapon. In 2018 China's retaliatory 25% tariff cut US soybean exports to China sharply, Brazil filled the gap, and Washington offered its farmers up to $28 billion in trade aid, until the Phase One deal of 2020 restored purchases for a time.

In 2025 the sequence repeated at larger scale, as from May China bought almost no American soybeans and turned to Brazil and Argentina. At their meeting in Busan on October 30, 2025, Presidents Trump and Xi agreed a truce under which China would buy 12 million tonnes in late 2025, a deadline later extended toward February 2026, and at least 25 million tonnes a year in 2026-28.

Washington announced $12 billion of Farmer Bridge Assistance in December 2025, mostly paid per acre to growers of row crops by the end of February 2026. Shipments to China in the first quarter of 2026 were 57% higher than a year earlier, and by mid-September China had bought more than half of its 2026 commitment, by Bloomberg's count, and the truce was extended in September 2026 to January 10, 2027.

13e. Regulation as Trade Policy

The European Union, self-sufficient in most staples and protected by the CAP, uses regulation as its trade instrument. Its tools include the Deforestation Regulation, limits on pesticide residues, bans on hormone-treated beef and most GM crops, and the 'mirror clauses' its farmers demand so that imports meet European standards. The EU-Mercosur agreement with Argentina, Brazil, Paraguay, and Uruguay was signed on January 17, 2026, and its trade part has applied provisionally since May 1, while the European Parliament has asked the EU's Court of Justice to rule on it.

China uses trade penalties as diplomacy: anti-dumping duties on Australian barley in 2020, a suspension of Canadian canola imports on plant-health grounds in 2019, and tariffs on Canadian canola in 2025, and it can reverse them for a price. Under a deal reached in Beijing on January 16, 2026, China agreed to cut its duty on Canadian canola seed from 84% to about 15% by March, and Canada agreed to admit up to 49,000 Chinese electric cars a year at a 6.1% tariff.

Module 13 Key Points

Trade Policy and Export Bans

• Farm trade is the least liberalized; the WTO's appeals body is idle, and in February 2026 the Supreme Court struck down emergency tariffs.

• Export bans export the shortage and breed each other, and the WTO has no enforceable rule against them.

• India's 2022-24 rice bans hit about 40% of world trade and pushed rice prices to their highest since 2008.

• China stopped buying US soybeans in 2025; at Busan it pledged 25 Mt a year for 2026-28, and Washington paid $12 billion.

• The EU regulates what it imports; China uses trade penalties as diplomacy and traded canola relief for Canadian car access in 2026.

Module 13 Quiz

Check Your Understanding

1. What did the Supreme Court decide about the 2025 tariffs in February 2026?

A) That the emergency-powers law does not authorize tariffs
B) That they were legal
C) That only Congress may set tariffs on farm goods, so farm tariffs were void
D) That tariffs on China could stay but those on allies must end within 150 days

2. What made the 2008 rice crisis a cascade?

A) A harvest failure across Asia's river deltas
B) Export bans
C) A shipping strike that closed the Strait of Malacca
D) Speculators cornering the Chicago rice futures market

3. When did India lift its ban on exports of non-basmati white rice?

A) In 2023
B) It has not
C) September 2024, with a floor price it dropped in October
D) In August 2026, together with its wheat ban, after a record harvest

4. What did China commit to at Busan in October 2025?

A) To end all tariffs
B) To stop buying from Brazil
C) To buy American beef and pork
D) To buy at least 25 million tonnes of US soybeans a year in 2026-28, after 12 million in late 2025

5. What did China agree with Canada in January 2026?

A) A full ban on Canadian canola oil and meal from March
B) A tariff war
C) To cut its canola seed duty to about 15%
D) A free-trade agreement covering all farm goods and electric cars

Module 14 — Hunger and Food Security

Who Does Not Eat, and Why, With Sudan and Gaza

Recommended Reading / Reference

Book: Amartya Sen, *Poverty and Famines* (1981)

Report: FAO and four other UN agencies, *The State of Food Security and Nutrition in the World 2026* (SOFI), July 21, 2026

Report: Global Network Against Food Crises, *Global Report on Food Crises 2026* (April 24, 2026)

Reference: Integrated Food Security Phase Classification (IPC) analyses for Sudan (June 2026) and Gaza (December 2025 and July 2026); UN Environment Programme (UNEP), *Food Waste Index Report 2024*

14a. The Numbers

Region	Undernourished, 2025	Moderate or severe food insecurity, 2025	Note
Africa	309 million (20.0%)	56.6%	Now home to more hungry people than any other region, a first; two-thirds cannot afford a healthy diet
Asia	292 million	20.3%	Numbers falling, led by South Asia's gains
Latin America and the Caribbean	Most of the remaining 44 million	22.9%	A healthy diet costs most here, 4.91 international dollars a day
Northern America and Europe	Small	8.7%	
World	645 million (7.8%), down from 8.1% in 2024	25.8%, down from 27.1%	32.7% cannot afford a healthy diet; about 510-520 million projected to be hungry in 2030

SOFI 2026. Undernourishment means eating too few calories over a year; moderate or severe food insecurity means being uncertain of getting enough to eat. International dollars adjust for purchasing power.

The UN's 2026 hunger report counts about 645 million people chronically undernourished in 2025, 7.8% of humanity, down from 8.1% in 2024 and the third annual decline in a row. Africa's rate fell to 20.0%, but with its population growing fast it now has more hungry people than Asia, 309 million against 292 million, for the first time.

A wider measure, moderate or severe food insecurity, covers 25.8% of the world's people and 56.6% of Africans. A healthy diet cost an average of 4.28 international dollars a day in 2025, and 32.7% of the world's people could not afford one. The report projects that about 510-520 million will still be hungry in 2030, against the goal of zero, and warns that the war in the Middle East, extreme weather, and aid cuts threaten even that.

14b. Acute Hunger, Sudan, and Gaza

Place	People in crisis or worse (IPC Phase 3+)	Famine (IPC Phase 5)	Driver	Latest analysis
World	266 million in 47 countries in 2025 (22.9% of those analyzed); 39 million in Emergency and 1.4 million in Catastrophe	Famine in Gaza and Sudan in 2025, the first year with famine in more than one country	Conflict for 147.4 million in 19 countries; weather for 87.5 million in 16	Global Report on Food Crises 2026 (April 24, 2026)
Sudan	19.5 million (41%) in February 2026-January 2027; more than 5 million in Emergency	Confirmed in El Fasher and Kadugli in November 2025; 14 areas at risk in 2026	War between the army and the Rapid Support Forces since April 2023	IPC update, June 2026
Gaza	1.4 million (67%) projected through December 2026; 212,000 in Emergency	Confirmed in August 2025; declared over in December 2025	War and restrictions on aid since October 2023	IPC update, July 23, 2026

The IPC classifies areas and households in five phases: Minimal, Stressed, Crisis, Emergency, and Catastrophe or Famine.

The Integrated Food Security Phase Classification (IPC) is the system the UN and aid agencies use to grade hunger, and famine is its fifth and worst phase. In 2025, for the first time, the IPC confirmed famine in two countries in the same year, and both were made by war rather than weather.

In Sudan's war between the army and the Rapid Support Forces (RSF), which began in April 2023, both sides blocked aid, looted harvests, and attacked markets, and by 2025 about 12 million Sudanese had been displaced. After the RSF took El Fasher, the last army stronghold in Darfur, in October 2025, the IPC confirmed famine there and in Kadugli in South Kordofan.

The IPC's June 2026 update found 19.5 million people, 41% of the population, in crisis or worse for February 2026 to January 2027. About 135,000 were in Catastrophe, a number the June update projected to reach about 200,000 in the June-October lean season, and 14 areas were at risk of famine, while in Ambro, in North Darfur, 52.9% of young children were acutely malnourished.

In Gaza, the war that began in October 2023 destroyed farms, bakeries, and markets, and restrictions on aid starved the population until the IPC confirmed famine in Gaza City in August 2025. After the October 2025 ceasefire let more aid in, it declared in December that famine was over, though the whole Strip remained in Emergency.

By July 2026 the IPC projected 1.4 million people, 67% of the population, in crisis or worse through December 2026, and 74,200 children needing treatment for acute malnutrition by April 2027, and it called the gains highly fragile because aid deliveries had been falling since February.

Sen's rule holds in both places, since neither famine was a failure of supply: Sudan exports sesame, gum arabic, and livestock, and Gaza sits beside food-exporting neighbors. Each was a failure of entitlement, made by armies that controlled who could get food.

14c. The Aid Collapse

The response system shrank as the need grew: in 2025 the United States, which had supplied roughly 40% of the World Food Programme's (WFP's) budget in recent years, dismantled the US Agency for International Development (USAID), and several European donors cut aid to pay for defense. The famine early-warning network that the United States funded went dark from January to June 2025.

The WFP estimated that 318 million people would face acute hunger in 2026, more than twice the 2019 number. It planned to reach the 110 million most vulnerable for $13 billion, but expected close to half that

sum, and it has cut rations for refugees and suspended school meals in several countries, so the system built after 1945 to prevent famine is now funded only to manage it.

14d. The Paradox

The world grows more than enough food and loses or wastes much of it: the FAO estimates that about 13% is lost between harvest and the shop, much of it in poor countries without cold stores and roads. UNEP estimates that 1.05 billion tonnes, about 19% of the food available to consumers, was wasted in 2022, most of it in homes.

Hunger in 2026 is therefore not mainly a production problem but a problem of distribution, income, and conflict. The hungry are hungry because they are poor, at war, or cut off, not because the grain does not exist. That is why a fertilizer shock matters, since it raises the price of what exists, and why the remedies are as much political as agricultural.

Module 14 Key Points

Hunger and Food Security

• SOFI 2026 counts 645 million undernourished in 2025, 7.8%; Africa, with 309 million, now has more hungry people than Asia.

• The Global Report on Food Crises counted 266 million in acute food insecurity in 2025, with famine in Gaza and Sudan.

• Sudan's war produced famine in El Fasher and Kadugli; 19.5 million Sudanese face crisis or worse into early 2027.

• Gaza's famine was confirmed in August 2025 and declared over in December; 1.4 million are projected in crisis through 2026.

• Aid cuts left the WFP expecting about half of its $13 billion plan for 2026.

• About 13% of food is lost before shops and 19% wasted after, while 32.7% of people cannot afford a healthy diet.

Module 14 Quiz

Check Your Understanding

1. How many people were undernourished in 2025, by SOFI 2026?

A) About 645 million, 7.8% of humanity, with Africa now home to the most
B) About 2 billion
C) About 100 million, mostly in Asia
D) About 1.2 billion, a seventh of humanity

2. What did the IPC conclude about Gaza in December 2025?

A) Famine spread south
B) Famine was over, though the whole Strip remained in Emergency
C) Gaza was food-secure
D) Famine conditions had worsened to the highest level ever recorded anywhere

3. Where did the IPC confirm famine in Sudan in November 2025?

A) Across all of Sudan and South Sudan
B) In Khartoum and Port Sudan, the two capitals
C) In Darfur's refugee camps in Chad
D) El Fasher and Kadugli

4. What share of its planned 2026 budget did the WFP expect to receive?

A) All of it, after new pledges from Europe
B) A tenth, after the US withdrew entirely
C) Twice its target, because of the Hormuz shock
D) About half

5. Why does the module call hunger a problem of distribution, income, and conflict rather than production?

A) Grain is scarce
B) Farmers grow too much
C) The world grows enough food; the hungry are poor, at war, or cut off, and a third of people cannot afford a healthy diet
D) Food waste has been eliminated

Module 15 — Nutrition, Diets, and the Food Industry

What People Eat, Who Sells It, and the Argument Over Ultra-Processed Food

Recommended Reading / Reference

Book: Chris van Tulleken, *Ultra-Processed People* (2023)

Paper: Kevin Hall and colleagues, 'Ultra-processed diets cause excess calorie intake and weight gain' (*Cell Metabolism*, 2019)

Paper: Melissa Lane and colleagues, umbrella review of ultra-processed food and health (*BMJ*, February 2024)

Reference: US Departments of Health and Human Services and Agriculture, *Dietary Guidelines for Americans 2025-2030* (January 7, 2026); *The Lancet* series on ultra-processed food (November 2025); Gallup, GLP-1 use survey (July 2026)

15a. The Nutrition Transition

Stage	Diet	Where	Health pattern
Subsistence	A staple grain or tuber with little meat, fat, or sugar	The poorest rural places	Undernutrition; stunting of about 150 million children; missing micronutrients
Rising income	More vegetable oil, sugar, and meat; processed staples	South Asia, Africa's cities, Southeast Asia	The double burden: stunting and obesity in the same communities
Middle income	Meat and dairy rising fast; packaged food; sugary drinks	China, Latin America, the Middle East	Obesity and diabetes rising fastest
High income	Ultra-processed food more than half of calories; meat demand flat	The US, the UK, Canada, Australia	Obesity in a quarter to two-fifths of adults; diet a leading cause of death
Post-transition, emerging	Less processed food, less meat, GLP-1 drugs	Segments of rich countries	The first reversal

As countries grow richer, their diets follow a predictable path, from staples to oils and sugar, then to meat and dairy, then to packaged and ultra-processed food, and the world now carries both ends at once. About 890 million adults were obese in 2022 and 2.5 billion overweight, by the World Health Organization's count, while about 150 million children under five are stunted.

Many countries, among them Mexico, Egypt, South Africa, and India, carry both problems in the same cities, the 'double burden' of malnutrition. The Global Burden of Disease study ranks poor diet among the leading causes of death, through heart disease, diabetes, and cancer. The transition is also the demand engine behind the rest of this course, since rising meat and dairy consumption in Asia and Africa is what moves the grain, soybean, and fertilizer markets.

15b. Ultra-Processed Food

Ultra-processed foods are industrial formulations of refined starches, sugars, oils, and additives, such as soft drinks, packaged snacks, reconstituted meats, and most breakfast cereals. The term comes from

NOVA, a classification devised by the Brazilian nutrition scientist Carlos Monteiro, which sorts foods by how much they are processed rather than by their nutrients.

By the US Centers for Disease Control and Prevention (CDC), ultra-processed foods supplied about 55% of the calories Americans ate in 2021-23, and studies put Britain's share at a similar level, while their share is rising nearly everywhere else.

Governments have begun to act: Chile's black warning labels, introduced in 2016, were followed by a fall of about a quarter in purchases of sugary drinks, and Mexico, Colombia, and Brazil adopted similar labels. Britain restricted advertising of less healthy foods on television and online from January 2026, and California passed a law in 2025 to phase the most harmful ultra-processed foods out of school meals by 2035.

The US Dietary Guidelines for 2025-2030, issued on January 7, 2026, tell Americans to 'eat real food', to avoid highly processed foods, and to treat no amount of added sugar as healthy. Their expert panel, however, declined to make a formal recommendation on ultra-processed food, citing the quality of the research.

15c. The GLP-1 Demand Shock

The first pharmacological force on food demand arrived in 2023-26, as GLP-1 drugs such as semaglutide and tirzepatide, which mimic a gut hormone that signals fullness, cut appetite sharply. In Gallup's 2026 survey 11% of American adults said they were taking one to lose weight and 15% had done so at some point, and the first GLP-1 pill for weight loss reached American pharmacies in January 2026.

Users eat less and shift away from snacks, sweets, and alcohol toward protein and produce, and studies of shopping data find that households with a user cut their grocery spending by about 6% within six months, with the largest cuts in chips, sweets, and baked goods. Food companies from Nestlé to Conagra have launched products aimed at users, and the effect runs opposite to the nutrition transition, down the pyramid rather than up it.

15d. Argued: Is Ultra-Processed Food a Distinct Health Risk?

The case that it is, as Monteiro, van Tulleken, and the authors of *The Lancet*'s 2025 series make it, rests on a growing body of evidence. In Kevin Hall's 2019 trial at the US National Institutes of Health, twenty volunteers ate about 500 more calories a day on an ultra-processed diet than on an unprocessed one matched for sugar, fat, and fiber, and gained weight within two weeks.

A 2024 umbrella review in the *BMJ*, covering about 10 million people, linked higher consumption to 32 harmful outcomes, with the strongest evidence for deaths from heart disease, type 2 diabetes, and common mental disorders. Supporters argue that softness, energy density, and engineered flavor make people eat faster and more, so the category itself is the problem.

The case that it is not, as the industry, many food scientists, and some nutrition researchers make it, rests on the category's breadth. NOVA puts packaged wholegrain bread, flavored yogurt, and infant formula in the same group as soda and candy.

Most of the evidence is observational and may reflect income and lifestyle rather than processing, and once sugar, salt, fat, and calories are accounted for, processing may add little. Britain's Scientific Advisory Committee on Nutrition judged in 2023 that the associations were concerning but the evidence uncertain, and critics add that cheap, safe, shelf-stable food is what feeds the poor.

The evidence points between the two, because trials are few but point the same way: a British trial published in 2025 found that people lost about twice as much weight on minimally processed versions of a healthy diet as on ultra-processed versions of the same diet. The observational links are consistent, but they cannot settle what causes them.

The course's reading is that the evidence justifies concern about the energy-dense, sugary, and salty core of the category more than about processing as such. Policy should target those products through warning labels, limits on marketing to children, and taxes on sugary drinks, rather than the NOVA label as a whole.

15e. The Manufacturers and the Retailers

Company	Home	Main categories	2025-26 note
Nestlé	Switzerland	Coffee, pet food, infant formula, confectionery, frozen food	Agreed on July 23, 2026 to sell half of its remaining waters business
PepsiCo	United States	Snacks (Frito-Lay), drinks, Quaker	Falling snack volumes in the US; an activist investor took a stake in 2025
Unilever	Britain	Hellmann's, Knorr, and other foods	Spun off its ice-cream arm as the Magnum Ice Cream Company in December 2025
Mars	United States, private	Confectionery, pet food, and now snacks	Completed its purchase of Kellanova (Pringles, Cheez-It) for about $36 billion in December 2025
Kraft Heinz	United States	Packaged staples and sauces	Paused its planned split in two in February 2026 under a new chief executive
Mondelez, Ferrero, Coca-Cola, General Mills, Danone	US, Italy, France	Biscuits, chocolate, drinks, cereal, dairy	Ferrero bought WK Kellogg in 2025; cocoa costs squeezed chocolate makers
Walmart, Costco, Kroger, Aldi, Lidl, Tesco	US, Germany, Britain	Retail	Walmart sells about a quarter of US groceries; discounters and store brands keep gaining

Food manufacturers turn commodities into brands and keep the largest share of the retail food dollar. In rich countries their volumes have stalled or fallen, under the weight of GLP-1 drugs, fatigue with the price rises of 2022-23, and the backlash against ultra-processed food. They have answered with price rises, growth in emerging markets, and a wave of portfolio surgery, as the table shows.

Module 15 Key Points

Nutrition, Diets, and the Food Industry

• About 890 million adults are obese and 150 million children stunted, often in the same countries: the double burden.

• Ultra-processed food supplies about 55% of US calories; Chile's warning labels cut sugary-drink purchases by about a quarter.

• In Gallup's 2026 survey 11% of US adults were taking a GLP-1 drug to lose weight, and 15% had ever done so.

• Hall's 2019 trial found about 500 extra calories a day on ultra-processed food, but most evidence is observational.

• The course's reading: target the energy-dense, sugary, salty core of ultra-processed food with labels, marketing limits, and drink taxes.

• Manufacturers face falling rich-world volumes and are reshaping: Mars bought Kellanova, Unilever spun off ice cream, and Kraft Heinz paused its split.

Module 15 Quiz

Check Your Understanding

1. What is the 'double burden' of malnutrition?

A) Stunting and obesity in the same population
B) Two famines
C) Obesity in adults and in children within the same rich country
D) Hunger caused by drought and war together in one region

2. What share of the calories Americans eat comes from ultra-processed food, by the CDC's 2021-23 data?

A) A tenth
B) About 55%, more than half
C) A quarter
D) Nearly all, about 90%, since most food is now packaged

3. What did Kevin Hall's 2019 inpatient trial find?

A) People ate about 500 more calories a day on an ultra-processed diet
B) No difference in intake
C) People lost weight on processed food
D) Ultra-processed food caused diabetes within two weeks in most volunteers, ending the trial early

4. What share of US adults said they were taking a GLP-1 drug for weight loss in Gallup's 2026 survey?

A) Under 1%
B) About 40%, mostly over 65
C) About a quarter, after prices fell
D) About 11%

5. What is the course's reading on ultra-processed food?

A) It is harmless
B) Ban it in schools
C) The category is too broad to regulate as one thing, but the evidence justifies targeting energy-dense, sugary, salty products
D) Only sugar matters

Module 16 — The Geopolitics of Food

Food as Weapon and Vulnerability, With the Black Sea

Recommended Reading / Reference

Report: Chatham House, *Chokepoints and Vulnerabilities in Global Food Trade* (2017)

Reference: UN and Joint Coordination Centre records of the Black Sea Grain Initiative (2022-23); Ukrainian Agrarian Council and Agriculture Ministry statements (July-September 2026); Land Matrix database of large land deals; the Center for Strategic and International Studies (CSIS), Global Food and Water Security Program

16a. The Black Sea

Before 2022 Ukraine and Russia together supplied more than a quarter of the world's wheat exports, most of its sunflower oil, and much of its maize and fertilizer, through ports on the Black Sea. Russia's invasion closed Ukraine's ports in February 2022 and sent the price of wheat up, so that for Egypt, Lebanon, Tunisia, and much of Africa the war was a bread crisis.

The Black Sea Grain Initiative, brokered by the UN and Turkey in July 2022, let about 33 million tonnes of Ukrainian food out before Russia quit it in July 2023. Ukraine then opened its own corridor, protected by sea drones and missiles that pushed Russia's fleet away from the western Black Sea, and by 2024 its seaborne exports were back near prewar levels.

Russia, whose own exports never stopped and whose harvests set records, used cheap grain as diplomacy. It promised free shipments to six African states in 2023 and undercut Ukraine in its markets.

In 2026 the ports became targets again. More than 90% of Ukraine's farm exports move through three ports in the Odesa region, and Russian strikes on July 10-12 hit terminals at Chornomorsk, where Kernel, Ukraine's largest grain exporter, halted operations, and the farmers' union estimated that a third of sea-export capacity had been lost. European wheat futures rose 7% on July 15 to their highest since February 2025, and on September 1 the Ukrainian Agrarian Council told exporters to assume the deep-water ports would not reopen before December or January.

The fallbacks cannot carry the load: Ukraine's grain exports fell to 774,000 tonnes in August, about a third less than a year earlier, and the Danube, rail, and road can move about 2.5-3 million tonnes a month against about 5 million needed. About 80 ships were waiting to enter the Danube at the end of August, and the detours add $50 a tonne or more.

The agriculture minister put the farm products available for export at more than 60 million tonnes and warned that lost income would cut plantings of winter wheat for 2027. A breadbasket at war exports at the mercy of whoever controls its sea, and its farmers decide next year's crop on this year's prices.

16b. China's Food-Security Doctrine

China feeds about a sixth of humanity on less than a tenth of the world's arable land and treats food security as regime security, through a doctrine with five parts. First, it aims at self-sufficiency in rice, wheat, and maize, enforced by minimum purchase prices and a 'red line' that keeps about 120 million hectares (300 million acres) in farming, and its grain harvest passed 700 million tonnes for the first time in 2024.

Second, it holds the world's largest stockpiles, and third, it tolerates dependence on imported soybeans, about 115 million tonnes in 2026/27, managed by spreading purchases across Brazil, Argentina, and the United States. Fourth, it controls its own import chain through COFCO, Syngenta, and port and farmland investments abroad, and fifth, since 2023 it has approved GM maize and soybeans to raise yields.

The 2025 trade war showed the doctrine at work: when the United States raised tariffs, China stopped buying American soybeans, shifted to Brazil, and then sold its return as a concession at Busan. Its limits on fertilizer exports and its purchase of Syngenta apply the same doctrine upstream.

16c. The Gulf, India, Russia, and the United States

Actor	Strategy	Instruments	Examples
Gulf states	Import most food; buy into the supply chain	Stakes in traders, farmland abroad, strategic reserves	Saudi Arabia's SALIC owns 80% of Olam Agri, and Abu Dhabi's ADQ 45% of Louis Dreyfus; Saudi Arabia ran down its own water-hungry wheat farming from 2008, and Arizona cancelled a Saudi-owned alfalfa farm's state leases in 2023
China	Self-sufficiency in staples; control of the chain	COFCO, Syngenta, stockpiles, port stakes	Brazil's soy corridors; Peru's Chancay port, opened in 2024
India	Self-sufficiency, with export bans as price policy	Minimum support prices, free grain, export controls	Rice bans in 2022-24 and a wheat ban until August 2026
Russia	Grain and fertilizer as leverage	Export quotas and taxes; cheap and gifted grain; attacks on Ukraine's ports	Wheat exports cut to about 40 Mt in 2026/27, a five-year low, by USDA's October estimate
United States	Long the food power; now on the receiving end	Food aid, tariffs, sanctions, biofuel mandates	China's 2025 soybean boycott, the end of USAID, and a forecast $47.4 billion of farm payments in 2026
European Union	Regulate how the world grows for it	The Deforestation Regulation, residue and GM rules, mirror clauses	Traceability demanded of Brazilian soy and Ivorian cocoa

The United States, the largest agricultural exporter for most of a century, used food as aid and as leverage from the Marshall Plan onward, but in 2025-26 it found itself on the other side. Its soybean farmers were cut off by China, its tariffs raised its own farmers' costs, its aid agency was dismantled, and its farm economy came to depend on emergency payments.

The Gulf states, which import most of their food, have bought into the supply chain instead. India uses export bans as domestic price policy and exports its inflation, and Russia uses quotas, taxes, and gifts of grain to reward friends and punish rivals. The Land Matrix database records tens of millions of hectares of large international land deals since 2000, much of them in Africa and Eastern Europe, and the newest form is farming other countries' water.

16d. Inputs and Chokepoints as Weapons

Chokepoint	What passes	2023-26
Strait of Hormuz	Gulf urea, ammonia, and sulfur; the Gulf's food imports	Closed to most shipping from February 28, 2026, apart from a few weeks after June 17; Iran says it stays closed until its conditions are met
Bab el-Mandeb and the Suez Canal	Grain and oilseeds between the Atlantic and Asia and East Africa	Houthi attacks since late 2023; a declared Houthi blockade of Saudi Arabia from July 20, 2026
Odesa's ports and the Turkish Straits	Ukrainian and Russian wheat, maize, and sunflower oil	Ukraine's deep-water ports closed by strikes from July 2026; Turkey raised transit fees about 15% on July 1
Panama Canal	American grain bound for Asia	Drought cut transits in 2023-24
Strait of Malacca	Asian rice and palm oil	
The Mississippi, the Paraná, and the Rhine	Barges to export ports	Low water on the Mississippi in 2022-23 and the Paraná in 2021-24; the Rhine at a record low in September 2026

The new weapons are inputs and chokepoints: fertilizer, as 2022 and 2026 showed, is a lever held by Russia and the Gulf, and whoever controls the gas, the ports, and the straits controls the harvest a season later. Food trade's chokepoints are the same ones the shipping industry watches, and in 2026 Hormuz, the Red Sea, Ukraine's ports, and the Rhine were constrained at the same time.

Module 16 Key Points

The Geopolitics of Food

• Ukraine and Russia supplied over a quarter of world wheat exports before 2022; the UN-Turkish corridor moved about 33 Mt before Russia quit.

• Strikes on Odesa's ports from July 2026 cut sea-export capacity by about a third; August grain exports fell to 774,000 tonnes.

• Russia's wheat exports fall to about 40 Mt in 2026/27, a five-year low, while it uses grain as diplomacy.

• China feeds a sixth of humanity on under a tenth of the world's arable land, behind a 120-million-hectare red line.

• The Gulf buys supply chains: Abu Dhabi owns 45% of Louis Dreyfus and Saudi Arabia's SALIC 80% of Olam Agri.

• Chokepoints are the new weapons: in 2026 Hormuz, the Red Sea, Odesa's ports, and the Rhine were constrained at once.

Module 16 Quiz

Check Your Understanding

1. Before the 2026 strikes, through which ports did most of Ukraine's farm exports pass?

A) The Danube river ports of Reni and Izmail
B) Three in the Odesa region
C) Polish rail terminals on the western border
D) Romania's port of Constanța, by agreement

2. What did Ukraine's Agrarian Council tell exporters on September 1, 2026?

A) That the war had ended
B) To ship by air
C) To assume deep-water ports would not reopen before December or January
D) That Turkey would escort grain ships through a new UN corridor from October, ending the queue at the Danube

3. What is the core of China's food-security doctrine?

A) Self-sufficiency in staple grains, a farmland red line, huge stockpiles, and tolerated dependence on imported soybeans
B) Importing all its grain
C) Buying American farmland
D) Leaving food to the market

4. Which Saudi company took 80% of Olam Agri in 2026?

A) Saudi Aramco, through its trading arm
B) The Public Investment Fund directly
C) Almarai, the dairy group
D) SALIC

5. What happened to Russia's wheat exports in USDA's October 2026 forecast?

A) Record
B) Cut to 40 Mt, a five-year low
C) Banned by Moscow to protect domestic prices after a drought
D) Raised to 50 Mt as Ukraine's ports closed

Module 17 — Seven Food Systems

The Regions That Feed and Are Fed

Recommended Reading / Reference

Reference: USDA Economic Research Service farm income forecasts (September 3, 2026); Embrapa, Brazil's agricultural research company; the European Commission's CAP data; China's annual No. 1 Central Document on rural policy; India's Agriculture Census; the African Development Bank and the 2024 Africa Fertilizer and Soil Health Summit

System	Role	Structure	Strengths	Vulnerabilities	Decision in 2026
United States	The second-largest agri-food exporter: maize, soybeans, wheat, meat, nuts	About 1.9 million farms; about half of output from the largest few percent	Yields, the Mississippi and the railroads, technology, capital	Dependence on federal payments after losing China; water in the West; a lapsed farm bill	Whether the farm economy is rebuilt on markets or on aid
Brazil	The largest exporter of soybeans, sugar, coffee, orange juice, beef, and chicken; second in maize	Large Cerrado farms; Embrapa's tropical agronomy; two crops a year	Land, climate, low costs, China as a customer	Deforestation and European rules; river logistics in drought; dependence on China	How far to push into the Cerrado and the Amazon, and under whose rules
European Union	The largest agri-food exporter by value: wine, dairy, processed food	About 9 million farms; intensive northwest, extensive south and east	Standards, brands, processing	Farmer revolt against green rules; drought in 2022 and 2026; imported feed and fertilizer	Whether the CAP after 2027 pays for change or for the status quo
China	The largest producer of grain, pork, vegetables, and fish; the largest importer of soybeans	About 200 million small farms of well under a hectare each, plus state farms	Stockpiles, subsidies, state capacity	Less than a tenth of the world's arable land for a sixth of its people; a dry north; an aging farm workforce	Whether GM crops and larger farms keep the self-sufficiency line
India	The largest producer of milk and pulses and the largest rice exporter	About 146 million holdings averaging about 1 hectare; free grain for 813 million	Self-sufficiency; huge public stocks	Falling groundwater, heat, a weak 2026 monsoon, farm politics	Whether Punjab and Haryana move off free-power rice before the aquifers fail
Sub-Saharan Africa	A net food importer with much of the world's unused farmland	Smallholders of 1-2 hectares; about 5% of cropland irrigated	Land, labor, the largest yield gap to close	Infrastructure, conflict, climate, fertilizer costs, post-harvest losses	Whether the missing Green Revolution arrives, and on whose fertilizer
Middle East and North Africa	The most import-dependent region, buying most of its grain	Irrigated river valleys and oases; Gulf capital	Money in the Gulf; the Nile	Water; Black Sea wheat; Gulf fertilizer and the closed strait	Whether food security is bought abroad or grown at an unsustainable water cost

EU exports counted outside the bloc. Sources: USDA, Eurostat, India's Agriculture Census 2015-16, FAO.

17a. The Breadbaskets

Three systems feed most of the importing world: the European Union is the largest agri-food exporter by value, selling wine, dairy, and processed food outside the bloc, and the United States and Brazil follow, with the United States holding the most productive farmland and the best inland logistics on earth.

American farming's vulnerabilities in 2026 are water in the West, a farm bill that lapsed on September 30, and dependence on federal money. USDA forecasts net farm income of $158.4 billion for 2026, down 2.6%, of which $47.4 billion comes from government payments.

Brazil is the system that grew fastest, because Embrapa, the state agricultural research company, made the acid soils of the Cerrado farmable from the 1970s, and two crops a year on large farms undercut competitors. Brazil now leads world exports of soybeans, sugar, coffee, orange juice, beef, and chicken, and USDA projects a soybean crop of 186 million tonnes for 2026/27. The cost has been forest, which Europe's rules now target, and the Black Sea, Australia, Canada, and Argentina round out the exporters.

17b. The Giants Who Feed Themselves

China and India produce the most of nearly everything and export relatively little, and China's roughly 200 million small farms, with state farms and growing agribusinesses, produce about a quarter of the world's grain and half its pork. The state stockpiles, subsidizes, and defends a red line of farmland, and its harvest passed 700 million tonnes in 2024. Its weaknesses are scarce land and water and an aging rural workforce, and its answers are GM crops, larger farms, and control of its import chain.

India's farms average about a hectare, yet they produce the world's most milk and pulses and, by USDA's estimate, as much rice as China, under state purchases at minimum prices, free electricity for pumping, and free grain for 813 million people. Its weaknesses are falling groundwater in the northwest, heat, and a monsoon that ended 12.6% short in 2026.

India's farm politics forced the repeal of three reform laws in 2021, yet it is also a large exporter when it chooses to be: it lifted its wheat export ban in August 2026 after a record harvest and is projected to export a record 25 million tonnes of rice in 2026/27. Both giants use export controls as domestic price policy, which is one reason the world's rice and wheat trade is thin.

17c. Africa and the Importers

Sub-Saharan Africa is the paradox: it holds much of the world's uncultivated farmland and its fastest-growing population, yet it imports food worth tens of billions of dollars a year, because its cereal yields are about a fifth of those in the United States. Only about 5% of its cropland is irrigated, its farmers use a fraction of the fertilizer used elsewhere, and a large share of harvests is lost after the field.

The fertilizer shocks of 2022 and 2026 hit it hardest, and African governments meeting in Nairobi in 2024 pledged to triple domestic production and distribution of fertilizer by 2034. The answer every development bank proposes, fertilizer, seed, irrigation, roads, and storage, is the one the money rarely arrives for at scale.

The Middle East and North Africa are the mirror image: the world's most import-dependent region, buying most of its grain from the Black Sea and Europe and its fertilizer from the Gulf. Bread subsidies there are regime-survival policy, and in June 2024 Egypt raised the price of its subsidized loaf from 5 to 20 piasters, the first rise since the 1980s. The Gulf buys its way out, which Egypt, Yemen, Sudan, and the Maghreb cannot.

Module 17 Key Points

Seven Food Systems

• The EU is the largest agri-food exporter by value, then the US and Brazil; Brazil leads in soybeans, sugar, coffee, beef, and chicken.

• US net farm income is forecast at $158.4 billion in 2026, with $47.4 billion of it from government payments.

• China and India grow the most and export little; India's monsoon fell 12.6% short in 2026 as it lifted its wheat ban.

• Sub-Saharan Africa holds much of the world's unused farmland but irrigates about 5% of its cropland and uses little fertilizer.

• The Middle East and North Africa import most of their grain; Egypt quadrupled its subsidized bread price in 2024.

Module 17 Quiz

Check Your Understanding

1. What made Brazil's farm boom possible?

A) Small family farms and cooperatives in the south
B) Embrapa's agronomy
C) Government price supports modeled on the EU's CAP
D) European investment in Amazon ranching after 2000

2. Why is Sub-Saharan Africa a net food importer despite much of the world's uncultivated farmland?

A) Its farmland is infertile
B) It exports its food
C) Its population is falling, so farms are abandoned in most countries every year
D) Its yields are low, with little irrigation and fertilizer

3. What did Egypt do to its bread subsidy in June 2024?

A) Abolished it
B) Doubled the ration
C) Raised the subsidized price of a loaf fourfold, from 5 to 20 piasters, the first rise since the 1980s
D) Handed it to the army to run

4. How large is the typical Indian farm?

A) About 1 hectare
B) 10 ha
C) About 50 hectares, after consolidation
D) About 200 hectares, similar to the American Midwest

5. Which bloc is the largest agri-food exporter by value?

A) The United States, by a wide margin
B) Brazil, since overtaking the US in 2020
C) China, through its processed-food exports
D) The EU

Module 18 — The Technology Frontier

What Is Changing Farming, and What Was Claimed

Recommended Reading / Reference

Reference: CGIAR, the global network of public agricultural research centers, and CIMMYT, the International Maize and Wheat Improvement Center, on drought-tolerant maize; the EU's 2026 regulation on new genomic techniques; Deere, Corteva, and Bayer technology disclosures; the bankruptcy filings of AeroFarms (2023), AppHarvest (2023), and Plenty (2025); Denmark's 2024 agreement on a livestock carbon tax

Technology	What it does	Status in 2026	Realistic impact	Verdict
Gene editing	Changes a crop's own genes without foreign DNA: disease resistance, drought tolerance, nutrition, shelf life	On sale in the US, Japan, and Argentina; India released two edited rice varieties in 2025; the EU's law applies from mid-2028	Faster, cheaper breeding	Real; the most consequential
Drought- and heat-tolerant varieties	Conventional and GM breeding for stress	Drought-tolerant maize on millions of African hectares; drought-tolerant wheat approved in Argentina, Brazil, and the US	Steadier yields more than higher ones	Real; the adaptation workhorse
Precision agriculture	Satellite guidance, variable-rate inputs, sensors, drones	Standard on large farms in the Americas, Europe, and Australia; rare on smallholdings	Lower input use; modest yield gains	Real where farms are large
Automation and AI	Weed-spotting sprayers, self-driving tractors, picking robots, yield forecasts	Sprayers sold widely; autonomy in limited use; fruit-picking robots slow	Herbicide savings where used; relief for labor shortages	Real but gradual
Biological inputs	Nitrogen-fixing microbes, biopesticides, biostimulants	Microbes applied on millions of US acres	Replace part of synthetic nitrogen	Real, but oversold
Vertical farming	Stacked hydroponic shelves under light-emitting diodes (LEDs)	Bankruptcies of AeroFarms and AppHarvest (2023), the closure of Bowery (2024), and Plenty's bankruptcy (2025)	Greens and herbs near cities; no grain	A niche
Alternative proteins	Plant-based and cultivated meat; precision-fermented dairy proteins	Plant-based sales down; cultivated meat tiny and banned in several places	Marginal beside a 370 Mt meat market	Oversold
Digital tools for smallholders	Advice, credit, insurance, and prices by phone	Growing in India, Kenya, Nigeria	Gains where roads and markets exist	Real; the smallholder frontier
Methane reduction	Feed additives, seaweed, breeding, vaccines in development	The additive Bovaer approved in the EU (2022) and the US (2024); Denmark taxes livestock emissions from 2030	Cuts cattle methane; no yield gain	Real; slow uptake
Soil-carbon markets	Pay farmers for practices that store carbon	Corporate programs; measurement disputed	Uncertain	Unproven

18a. What Is Real

The technologies most likely to change farming in the next decade are unglamorous, and gene editing is the most consequential, because it makes breeding faster and cheaper and, under most countries' rules, avoids the cost of GM regulation (Module 6). Its first products are on sale, and its pipeline includes disease-resistant wheat, drought-tolerant rice, and non-allergenic peanuts.

Drought- and heat-tolerant varieties from conventional and GM breeding are the adaptation workhorse, already grown on millions of African hectares. Precision agriculture and automation are real where farms are large: Deere reported that its camera-guided sprayers cut herbicide use by an average of 59% on more than a million acres in 2024, but such tools barely reach the world's 500 million smallholdings.

Biological inputs, such as microbes that fix nitrogen for maize, substitute for part of the synthetic fertilizer farmers buy. Digital tools that bring advice, credit, insurance, and market prices to a phone may matter more for the yield gap than any machine.

Methane is the newest target: feed additives such as Bovaer cut the methane cattle belch without raising yields, so farmers adopt them only when paid or required. Denmark agreed in 2024 to tax livestock emissions from 2030, the first country to do so.

18b. What Was Oversold

Vertical farming raised billions on the promise of growing food in city warehouses and produced a run of failures, as AeroFarms and AppHarvest went bankrupt in 2023, Bowery closed in 2024, and Plenty filed for bankruptcy in 2025. The electricity to replace sunlight with light-emitting diodes costs more than most produce is worth, so only leafy greens and herbs pay, and grain cannot be grown indoors at any plausible price.

Alternative proteins fell far short of their boosters' forecasts (Module 8), and soil-carbon markets promise to pay farmers for storage that cannot yet be measured reliably.

The recurring claim that some technology will 'feed the world' misreads the problem, because the world already grows enough food (Module 14). The yield gap is a matter of fertilizer, seed, water, roads, and credit reaching the smallholders of Africa and South Asia, the Green Revolution's unfinished business rather than a new invention.

Module 18 Key Points

The Technology Frontier

• Gene editing speeds breeding and escapes most GM rules; the EU's 2026 law applies from 2028, and India released edited rice in 2025.

• Drought-tolerant varieties are the adaptation workhorse, already grown on millions of African hectares.

• Camera-guided spraying cut Deere users' herbicide use by about 59% in 2024, but it reaches large farms, not smallholdings.

• Vertical farming's failures, from AeroFarms in 2023 to Plenty in 2025, show that LEDs cannot replace sunlight for most crops.

• Denmark will tax livestock emissions from 2030; feed additives such as Bovaer cut cattle methane but add no yield.

• The world already grows enough; the yield gap is fertilizer, seed, water, roads, and credit reaching smallholders.

Module 18 Quiz

Check Your Understanding

1. Why is gene editing the most consequential frontier, on the module's account?

A) It makes breeding faster and cheaper and, under most countries' rules, escapes the cost of GM regulation
B) It grows food indoors
C) It replaces fertilizer
D) It eliminates pests from fields

2. Why did so many vertical farms fail?

A) City zoning
B) Lighting costs more than most produce is worth
C) Regulators banned indoor produce in most American and European cities after 2022
D) Consumers refused to buy produce grown under lights

3. What does Denmark plan for livestock emissions?

A) A ban on cattle
B) Subsidies only
C) A carbon tax on livestock from 2030
D) A requirement that every herd be fed seaweed by 2027, enforced by quarterly audits

4. What do biological inputs such as nitrogen-fixing microbes realistically do?

A) Replace part of synthetic nitrogen
B) Double yields on every field where they are applied
C) Replace all synthetic fertilizer within a decade at no cost
D) Sterilize the soil against weeds, cutting herbicide use to zero

5. Why does the module say the 'feed the world' claim misreads the problem?

A) Famines are weather
B) Technology is irrelevant
C) The world already grows enough; the yield gap is about fertilizer, seed, water, roads, and credit reaching smallholders
D) The world cannot grow enough

Module 19 — Where Things Stand, and What to Watch

Where Food Is Heading

Recommended Reading / Reference

Report: OECD-FAO, *Agricultural Outlook 2026-2035* (June 29, 2026)

Report: World Resources Institute, *Creating a Sustainable Food Future* (2019)

Reference: UN, *World Population Prospects 2024*; Global Report on Food Crises 2026; the FAO Food Price Index and USDA's WASDE, monthly

19a. Feeding Ten Billion

The UN's 2024 projections put the world's population at about 9.7 billion in 2050, up from about 8.3 billion in mid-2026. With incomes rising and diets shifting toward meat and dairy, the World Resources Institute estimated that the world needs about 56% more crop calories in 2050 than in 2010. That food has to come from land that cannot expand without cutting forest, water that is growing scarcer, and a climate that is cutting yields.

The arithmetic requires yields to keep rising, and their growth has slowed from more than 2% a year in the 1960s-80s to about 1%. The OECD-FAO Outlook expects cereal output to reach about 3.2 billion tonnes by 2035 at broadly stable real prices. It also puts a one-in-four chance on farm incomes in 2035 being lower than today if shocks keep arriving at their recent pace.

The gap can be closed on paper by raising yields in Africa and South Asia, cutting waste, shifting diets, and new technology, but every one of those is harder in practice than on paper.

19b. The Lesson of the Turning Points

The cases in this course share a shape: biofuel mandates and export bans made the crisis of 2008 (Module 2), a Russian export ban the crisis of 2011, a presidential decree Sri Lanka's harvest failure (Module 5), and a naval war the Black Sea's (Module 16). Election politics made India's rice bans (Module 13), armies and sieges made the famines in Sudan and Gaza (Module 14), a court ruling and a dense livestock sector made the Dutch nitrogen fight (Module 10), and a war in the Gulf made the fertilizer shock of 2026.

Every one was a policy or a war before it was a harvest, and the shocks were foreseeable, since the chokepoints are mapped, the lags are known, and the export-ban cascade has happened again and again. The poor paid for each one, because food takes 40-60% of their income and they carry little political weight. Sen's lesson, extended from famine to price, is that what people can command decides who eats, and that governments decide what people can command more often than weather does.

19c. The Dependencies and the Demand Shifts

The system's defining feature is what it depends on, starting with nitrogen made from natural gas, much of it shipped past a few chokepoints, so a war in the Gulf shuts fertilizer plants in Bangladesh. It relies on a

handful of exporters, traders, seed companies, and meatpackers, on irrigation from shrinking glaciers and aquifers, and on a climate warming past the thresholds its crops were bred for.

Its humanitarian backstop has been defunded, and its trade rules have no discipline on export bans. Each dependency is efficient in a stable world and a fault line in an unstable one, and 2026 tested several at once.

Demand is changing in ways the old models did not include, since fuel mandates take about a third of American maize and half of its soybean oil. GLP-1 drugs are the first medicine to cut food demand, among the one American adult in nine taking them for weight loss. The shift from beef to chicken makes the animal sector more efficient, while rising incomes in Asia and Africa keep total meat demand growing, and trade policy is redirecting flows faster than production can follow.

19d. What to Watch

Date	What to watch	Why it matters
October 14, 2026	US consumer prices for September	Whether food inflation, 2.7% a year in August, is picking up
November 3, 2026	US midterm elections	The Congress that will write or extend the farm bill and vote on trade
November 6, 2026	FAO Food Price Index for October	Whether the climb to 136.0 continues
Mid-December 2026	The earliest likely action in Congress on the farm bill	Conservation enrollment and some dairy programs lapsed on September 30
December 2026-January 2027	Ukraine's deep-water ports	The Agrarian Council's earliest date for reopening; plantings of winter wheat for 2027
December 30, 2026	The EU Deforestation Regulation applies to large companies	Traceability for soy, cattle, palm oil, cocoa, coffee, rubber, and wood
January 1, 2027	Without a farm bill, US dairy support reverts to a 1949 law	The 'dairy cliff' that forces Congress to act
January 10, 2027	The extended US-China truce ends unless renewed	China's commitment to buy 25 Mt of US soybeans a year
January-March 2027	El Niño's expected peak	Southern Africa's maize, India's winter crops, Australian wheat, and palm oil yields a year later
Spring 2027	Northern fertilizer buying with the Strait of Hormuz still closed	Urea prices, which analysts expect to stay high into at least early 2027
June 30, 2027	The EU Deforestation Regulation applies to small companies	
Mid-2028	The EU's rules for gene-edited crops apply	Category 1 edits treated like conventional crops
Ongoing	H5N1 in dairy cattle; screwworm at the Mexican border; IPC updates on Sudan and Gaza; India's export decisions	The pandemic risk, the beef supply, the famines, and the thinnest market

19e. The Last Word

The food system is the largest thing humanity does: it employs about a quarter of the world's workers, uses more than a third of its land and 72% of the fresh water it withdraws, and produces about a third of its greenhouse gases. It is organized as a chemistry experiment with a supply chain: nitrogen from gas, seed from a few companies, and grain from a few breadbaskets, moved by a few traders past a few chokepoints to 8.3 billion people, of whom 645 million do not get enough.

It feeds more people better than at any time in history, and it broke in 2008, 2011, and 2022 in the same way each time, with a shock in one place amplified by bans and energy and landing on the poor. In 2026 a war closed the strait that carries much of its nitrogen, and a strong El Niño is gathering in the Pacific. The question the course leaves open is whether a system this efficient and this fragile can be made resilient before the next shock, or only after it.

Module 19 Key Points

Where Things Stand, and What to Watch

• The UN projects about 9.7 billion people by 2050; OECD-FAO expects cereal output of about 3.2 billion tonnes by 2035.

• Every turning point was a policy or a war before it was a harvest: bans, mandates, decrees, sieges, and closed straits.

• The system depends on gas-based nitrogen, a few exporters and traders, shrinking irrigation, and straits that 2026 constrained at once.

• Watch December 30 for the EU's deforestation rules, January 10, 2027 for the US-China truce, and El Niño's peak in early 2027.

• The open question is whether a system this efficient and this fragile can be made resilient before the next shock.

Module 19 Quiz

Check Your Understanding

1. What do the module's turning points have in common?

A) Each was caused by a drought in a single breadbasket
B) Weather
C) Each began with a crash in oil prices that cut farm incomes worldwide
D) Each was a policy or a war first

2. What happens on December 30, 2026?

A) The farm bill expires
B) The EU's deforestation rules start to apply to large companies
C) India bans rice exports
D) The UN's food price index is rebased to 2024-26, cutting reported prices by a third

3. Why does January 10, 2027 matter for food trade?

A) Mercosur ratification
B) Russia's export quotas
C) Brazil's harvest ends
D) The extended US-China truce ends unless renewed again, putting China's soybean purchase commitments at risk

4. By how much did the World Resources Institute estimate crop calories must rise between 2010 and 2050?

A) About 10%, since diets are shifting to plants
B) About 200%, tripling to feed Africa's growth
C) About 56%
D) Zero, if waste is halved by 2030 as the UN goal requires

5. What is the course's closing question?

A) Whether a fragile system can be made resilient in time
B) Who will win the soybean war
C) Whether the world can physically grow enough food for ten billion people by 2050
D) Whether meat will be banned in the rich world by the 2040s, as some campaigners urge

Answer Sheet

Answers to every module's Check Your Understanding quiz.

Module	Answers
Module 1 Quiz	1. C 2. A 3. D 4. B 5. B
Module 2 Quiz	1. C 2. A 3. D 4. C 5. D
Module 3 Quiz	1. A 2. B 3. B 4. C 5. A
Module 4 Quiz	1. D 2. C 3. D 4. B 5. A
Module 5 Quiz	1. D 2. A 3. C 4. B 5. B
Module 6 Quiz	1. C 2. A 3. D 4. B 5. A
Module 7 Quiz	1. D 2. C 3. C 4. B 5. D
Module 8 Quiz	1. A 2. A 3. C 4. B 5. D
Module 9 Quiz	1. D 2. A 3. C 4. B 5. C
Module 10 Quiz	1. A 2. D 3. B 4. A 5. B
Module 11 Quiz	1. C 2. D 3. D 4. C 5. A
Module 12 Quiz	1. B 2. C 3. A 4. D 5. B
Module 13 Quiz	1. A 2. B 3. C 4. D 5. C
Module 14 Quiz	1. A 2. B 3. D 4. D 5. C
Module 15 Quiz	1. A 2. B 3. A 4. D 5. C
Module 16 Quiz	1. B 2. C 3. A 4. D 5. B
Module 17 Quiz	1. B 2. D 3. C 4. A 5. D
Module 18 Quiz	1. A 2. B 3. C 4. A 5. C
Module 19 Quiz	1. D 2. B 3. D 4. C 5. A