

Mars agriculture, crops and regenerative biosystems

Move from packaged food to controlled biological production: light, water, nutrients, microbiology, yield, food safety and coupling with ECLSS.

Before you begin — Prerequisites: modules 00–34 as relevant. Every important symbol is defined at first use.

Mastery objectives

- connect principles to architecture or operational decisions
- repeat simple calculations and verify units and assumptions
- identify degraded modes, interfaces and uncertainty
- produce a verifiable procedure or plan

1. Plants are both food and life-support hardware

A crop consumes water, light, nutrients, volume and crew time, but produces edible biomass, oxygen and water vapor while taking up carbon dioxide. It must therefore be treated as a biological subsystem with measurable flows rather than as a simple garden.

2. Select crops by function, not terrestrial habit

A useful Mars crop combines edible yield, cycle time, nutrient density, disease resistance, non-edible biomass fraction and ease of harvest. Lettuce can provide fresh food quickly; grains or potatoes may contribute more calories but require different processing and infrastructure.

3. Light, photoperiod and electrical power

LED systems allow spectrum and photoperiod to be controlled. Agriculture then becomes an energy problem. A 50 m² crop area receiving an average 200 W/m² of light requires 10 kW of optical power before conversion losses, pumps and thermal control are included. Crop scheduling must therefore be coupled to the base power budget.

4. Water and nutrients in controlled loops

Hydroponics and controlled substrates allow water, pH, conductivity and nutrient concentrations to be measured. Closing the water loop saves resources but can also accumulate salts, organics and pathogens. A closed loop therefore means active quality control, not merely reuse.

5. Microbiology, disease and food safety

A closed greenhouse can amplify a plant pathogen rapidly. Seeds, substrates, surfaces, water and crew hands all belong to the microbiological system. Crops eaten raw deserve particular attention because food contamination directly reduces crew operational capability.

6. Waste, composting and circularity

Plant residues still contain carbon, nitrogen, phosphorus and water. A mature base will seek to recover those resources through composting, digestion or other processes compatible with biosafety. The challenge is preventing a recycling loop from also recycling toxins or unwanted organisms.

7. Closing nutrient loops without creating a biologically fragile system

A regenerative biosystem attempts to recycle water, nutrients and part of the waste stream, but 'closed' does not mean that no correction is ever required. Crops remove some ions faster than others, salts can accumulate, pH drifts and microorganisms transform nitrogen compounds. A Mars farm must therefore monitor conductivity, pH, dissolved oxygen, nutrient concentration and root health. Organic waste can become a resource after treatment, yet a poorly controlled loop can also spread pathogens or contaminants. The engineering goal is not perfect closure; it is a loop that is measurable, recoverable and divisible enough that one biological anomaly does not destroy the entire food-production system.

8. Light, heat and power: crops are also an electrical load

Inside a pressurized habitat, artificial lighting turns agriculture into a power-system problem. Nearly all electrical input eventually appears as heat that must be rejected, while photoperiod affects both plant development and the station load profile. A power reduction today can influence harvest mass weeks later. Designers must therefore link useful photon delivery, electrical efficiency, planted area, leaf temperature and thermal-control capacity. Sunlit greenhouses reduce part of the electrical burden but introduce different constraints: dust, optical transmission, insulation, day-night cycles and radiation protection. Agriculture and energy cannot be designed as independent systems.

9. From a botanical experiment to an operational food chain

A scientific crop experiment can succeed with a small number of plants; a food function must deliver predictable, harvestable and storable output that supports crew health. The chain therefore includes seed stocks, germination, transplanting, pollination, harvest, processing, preservation, cleaning and lot tracking. Crop diversity protects against one common failure but increases operational complexity. A Mars base also needs a food reserve because even an excellent farm can suffer disease, lighting failure or delayed growth. A robust architecture combines local production, stored food, diagnostic capability and procedures for isolating one growing compartment without contaminating the rest.

10. Worked example: crop area and fraction of need

NASA studies cite rough values of about 20–25 m² of crops to contribute the oxygen requirement of one person and around 50 m² to provide full dietary calories in some scenarios. For six people, 50 m²/person gives 300 m². If an early greenhouse provides only 90 m², it represents $90/300 = 30\%$ of that reference area and should be treated as a supplement rather than complete food autonomy.

Deeper engineering: convert food demand into area, light and power

A Martian greenhouse is not sized only in square metres. Food production has to be connected to light delivered to plants, electrical conversion efficiency and heat that must be rejected. Space crop experiments can study physiology and controlled systems, but they do not by themselves demonstrate food independence for a settlement. Moving from experimental plants to a food chain requires mass and energy accounting. [NASA Science — Space Crops](#)

Worked example. Imagine 120 m² of crop area receiving an average 220 W/m² of artificial light for 16 hours per day. Instantaneous optical power is $120 \times 220 = 26,400$ W, or 26.4 kW. Daily light energy is $26.4 \times 16 = 422.4$ kWh/day. If the combined electrical supply and lighting system converts 45% of electricity into useful photons, required electrical energy is $422.4 \div 0.45 \approx 938.7$ kWh/day. This is not an agronomic prescription; it shows why crop and lighting choices become major power-system decisions.

A large fraction of that energy also ends up as heat inside the greenhouse and must be moved or rejected. Agriculture therefore connects directly to the electrical grid and thermal-control system. A crop can be biologically attractive but operationally poor if its power, water, nutrient or labour demand exceeds available margins. Crop yield alone is never the whole mission metric. [NASA — Advanced Plant Habitat](#)

11. Progressive exercise

A 24 m² growth chamber yields on average 0.35 kg of edible biomass per m² in a 30-day cycle. Calculate monthly output and explain why kilograms alone cannot establish nutritional value.

Reasoned correction

Output is $24 \times 0.35 = 8.4$ kg of edible biomass per 30-day cycle, roughly 8.4 kg per month in this simplified model. That total says nothing about calories, protein, fat, essential amino acids, micronutrients, water content or the fraction that can actually be eaten. Eight kilograms of a water-rich crop do not replace eight kilograms of an energy-dense food. Losses, yield variability, harvest spacing, shelf life and the requirements of the complete menu also matter. A useful production metric therefore combines mass, food energy, nutritional quality and reliability over time.

Mini-project

Design a first-generation greenhouse for six people: crops, schedule, lighting, water, nutrients, microbial control, redundancy, waste handling, seed inventory and fallback to stored food.

Agriculture is a life-support process, not a garden project

A crop system on Mars must deliver food predictably while sharing power, water, nutrients, crew time and atmosphere with the habitat. A plant chamber that can grow impressive lettuce is not automatically a settlement food system. Engineers must ask how much edible mass is produced per area and per unit energy, how long each crop occupies the chamber, what fraction is inedible, how water and nutrients are recovered, and what happens when a disease or equipment failure destroys a growth cycle.

Crop choice is therefore a portfolio problem. Fast leafy vegetables can provide fresh food and psychological value but little dietary energy. Grains, potatoes or other staple crops can contribute more calories but require larger area, longer cycles and post-harvest processing. Legumes can add protein and interact with nitrogen management. A resilient plan combines crops with different functions rather than searching for one “best Mars plant.”

Biological variability must be respected. Plants respond to light, temperature, humidity, carbon dioxide, nutrient balance, root-zone oxygen and microbial conditions. The control system should track trends and define intervention thresholds without pretending that plants behave like identical mechanical loads. Agriculture on Mars is engineered ecology: it needs sensors and calculations, but also observation, quarantine and the ability to recover from living-system surprises.

Four crop-system ideas that prevent misleading productivity claims

Edible yield

Edible yield is the useful food mass produced per area, time or crop cycle. Total plant biomass can be much higher, so food-system sizing must distinguish leaves, stems, roots and other inedible material from the fraction people actually eat.

Harvest index

Harvest index is the fraction of total plant biomass that becomes the desired harvested product. It helps connect biological production to waste, recycling and food output.

Photosynthetically active radiation

Photosynthetically active radiation, often shortened to PAR, is the portion of light used most directly by photosynthesis. Lighting design must consider spectral quality and photon delivery, not only electrical wattage.

Crop failure reserve

A crop failure reserve is stored food, seed, spare capacity or schedule margin that allows the settlement to survive a lost harvest without immediately threatening crew nutrition.

Formula 1 — crop area from daily food demand and areal yield

Canonical quantitative mini-lessons

This block is the module quantitative reference; exercise values are pedagogical and must be replaced by mission data before any real decision.

Required crop area

$$A_{\text{crop}} = M_{\text{food}} / \text{yield_area}$$

1 — Concrete question

What does " $A_{\text{crop}} = M_{\text{food}} / \text{yield_area}$ " compute in "Required crop area"?

2 — Intuition without symbols

Required area depends on food demand and sustainable yield per unit area.

3 — Quantities

A_{crop} : crop area [m^2]; M_{food} : food output demand [kg/d]; yield_area : area yield [$\text{kg}/(\text{m}^2 \cdot \text{d})$]

4 — Formula

$$A_{\text{crop}} = M_{\text{food}} / \text{yield_area}$$

5 — Read aloud

Read " $A_{\text{crop}} = M_{\text{food}} / \text{yield_area}$ " by naming every operation, subscript and grouping explicitly.

6 — Symbols and meaning

A_{crop} : crop area [m^2]; M_{food} : food output demand [kg/d]; yield_area : area yield [$\text{kg}/(\text{m}^2 \cdot \text{d})$]

7 — Pronunciation

Say subscripts, powers, parentheses and Greek letters explicitly so the relation can be reconstructed without seeing the page.

8 — Units

A_{crop} [m^2]; M_{food} [kg/d]; yield_area [$\text{kg}/(\text{m}^2 \cdot \text{d})$]

9 — Convention

Keep the same frame, time basis, system boundary and sign convention throughout the substitution.

10 — Why this operation

Division relates a quantity to a coherent capacity, duration or reference.

11 — Assumptions

Numerator and denominator must describe the same scenario and the denominator must remain positive.

12 — Independent check

Multiplying the result by the denominator should reconstruct the numerator.

13 — Numerical case

With $M_{\text{food}} = 30 \text{ kg}/\text{d}$, $\text{yield_area} = 0.5 \text{ kg}/(\text{m}^2 \cdot \text{d})$: $A_{\text{crop}} = 30 / 0.5 = 60 \text{ m}^2$.

14 — Why the calculation works

Division relates a quantity to a coherent capacity, duration or reference.

15 — Verification

Multiplying the result by the denominator should reconstruct the numerator.

16 — Mental estimate

Comparing numerator and denominator scales predicts the result.

17 — Interpretation

Add biological margin and reserve capacity before fixing operational greenhouse area.

18 — What the result does not prove

The calculation proves neither that inputs are exact nor that the model remains valid outside the declared scenario; both require separate evidence.

19 — Sensitivity

The result rises with the numerator and falls as the denominator rises.

20 — Guided and autonomous exercises

Guided exercise. Recalculate this scenario: With $M_{\text{food}} = 20 \text{ kg}/\text{d}$, $\text{yield_area} = 0.4 \text{ kg}/(\text{m}^2 \cdot \text{d})$: $A_{\text{crop}} = 20 / 0.4$?

Detailed guided correction — open after trying

With $M_{\text{food}} = 20 \text{ kg/d}$, $\text{yield_area} = 0.4 \text{ kg}/(\text{m}^2 \cdot \text{d})$: $A_{\text{crop}} = 20 / 0.4 = 50 \text{ m}^2$. The decision must then be checked against the module margins and assumptions.

Autonomous exercise. Recalculate this scenario: With $M_{\text{food}} = 45 \text{ kg/d}$, $\text{yield_area} = 0.75 \text{ kg}/(\text{m}^2 \cdot \text{d})$: $A_{\text{crop}} = 45 / 0.75$?

Autonomous correction — open after trying

With $M_{\text{food}} = 45 \text{ kg/d}$, $\text{yield_area} = 0.75 \text{ kg}/(\text{m}^2 \cdot \text{d})$: $A_{\text{crop}} = 45 / 0.75 = 60 \text{ m}^2$. The decision must then be checked against the module margins and assumptions.

21 — Mission decision

Add biological margin and reserve capacity before fixing operational greenhouse area.

Daily lighting energy

$$E_{\text{light}} = P_{\text{density}} \times A_{\text{crop}} \times t_{\text{light}} / 1000$$

1 — Concrete question

What does “ $E_{\text{light}} = P_{\text{density}} \times A_{\text{crop}} \times t_{\text{light}} / 1000$ ” compute in “Daily lighting energy”?

2 — Intuition without symbols

Lighting converts power density, area and photoperiod into daily energy demand.

3 — Quantities

E_{light} : daily energy [kWh]; P_{density} : lighting power density [W/m^2]; A_{crop} : lit area [m^2]; t_{light} : photoperiod [h]

4 — Formula

$$E_{\text{light}} = P_{\text{density}} \times A_{\text{crop}} \times t_{\text{light}} / 1000$$

5 — Read aloud

Read “ $E_{\text{light}} = P_{\text{density}} \times A_{\text{crop}} \times t_{\text{light}} / 1000$ ” by naming every operation, subscript and grouping explicitly.

6 — Symbols and meaning

E_{light} : daily energy [kWh]; P_{density} : lighting power density [W/m^2]; A_{crop} : lit area [m^2]; t_{light} : photoperiod [h]

7 — Pronunciation

Say subscripts, powers, parentheses and Greek letters explicitly so the relation can be reconstructed without seeing the page.

8 — Units

E_{light} [kWh]; P_{density} [W/m^2]; A_{crop} [m^2]; t_{light} [h]

9 — Convention

Keep the same frame, time basis, system boundary and sign convention throughout the substitution.

10 — Why this operation

Multiplication converts a rate, fraction or specific quantity into a total.

11 — Assumptions

Factors must belong to the same scenario and their units must combine correctly.

12 — Independent check

Dividing the result by a non-zero factor should recover the product of the others.

13 — Numerical case

With $P_{\text{density}} = 250 \text{ W}/\text{m}^2$, $A_{\text{crop}} = 60 \text{ m}^2$, $t_{\text{light}} = 16 \text{ h}$: $E_{\text{light}} = 250 \times 60 \times 16 / 1000 = 240 \text{ kWh}$.

14 — Why the calculation works

Multiplication converts a rate, fraction or specific quantity into a total.

15 — Verification

Dividing the result by a non-zero factor should recover the product of the others.

16 — Mental estimate

Estimating each factor separately quickly predicts product scale.

17 — Interpretation

Verify this energy remains compatible with greenhouse power and heat-rejection budgets.

18 — What the result does not prove

The calculation proves neither that inputs are exact nor that the model remains valid outside the declared scenario; both require separate evidence.

19 — Sensitivity

A relative change in one factor transfers directly to the product when the others stay fixed.

20 — Guided and autonomous exercises

Guided exercise. Recalculate this scenario: With $P_{\text{density}} = 180 \text{ W/m}^2$, $A_{\text{crop}} = 50 \text{ m}^2$, $t_{\text{light}} = 14 \text{ h}$: $E_{\text{light}} = 180 \times 50 \times 14 / 1000$?

Detailed guided correction — open after trying

With $P_{\text{density}} = 180 \text{ W/m}^2$, $A_{\text{crop}} = 50 \text{ m}^2$, $t_{\text{light}} = 14 \text{ h}$: $E_{\text{light}} = 180 \times 50 \times 14 / 1000 = 126 \text{ kWh}$. The decision must then be checked against the module margins and assumptions.

Autonomous exercise. Recalculate this scenario: With $P_{\text{density}} = 300 \text{ W/m}^2$, $A_{\text{crop}} = 40 \text{ m}^2$, $t_{\text{light}} = 18 \text{ h}$: $E_{\text{light}} = 300 \times 40 \times 18 / 1000$?

Autonomous correction — open after trying

With $P_{\text{density}} = 300 \text{ W/m}^2$, $A_{\text{crop}} = 40 \text{ m}^2$, $t_{\text{light}} = 18 \text{ h}$: $E_{\text{light}} = 300 \times 40 \times 18 / 1000 = 216 \text{ kWh}$. The decision must then be checked against the module margins and assumptions.

21 — Mission decision

Verify this energy remains compatible with greenhouse power and heat-rejection budgets.

Crop-water make-up

$q_{\text{makeup}} = q_{\text{crop}} \times (1 - \text{eta}_{\text{recovery}})$

1 — Concrete question

What does “ $q_{\text{makeup}} = q_{\text{crop}} \times (1 - \text{eta}_{\text{recovery}})$ ” compute in “Crop-water make-up”?

2 — Intuition without symbols

Make-up equals the portion of crop water not recovered by the loop.

3 — Quantities

q_{makeup} : daily make-up [L/d]; q_{crop} : crop water circulation [L/d]; $\text{eta}_{\text{recovery}}$: recovered fraction [sans dimension]

4 — Formula

$q_{\text{makeup}} = q_{\text{crop}} \times (1 - \text{eta}_{\text{recovery}})$

5 — Read aloud

Read “ $q_{\text{makeup}} = q_{\text{crop}} \times (1 - \text{eta}_{\text{recovery}})$ ” by naming every operation, subscript and grouping explicitly.

6 — Symbols and meaning

q_{makeup} : daily make-up [L/d]; q_{crop} : crop water circulation [L/d]; $\text{eta}_{\text{recovery}}$: recovered fraction [sans dimension]

7 — Pronunciation

Say subscripts, powers, parentheses and Greek letters explicitly so the relation can be reconstructed without seeing the page.

8 — Units

q_{makeup} [L/d]; q_{crop} [L/d]; $\text{eta}_{\text{recovery}}$ [sans dimension]

9 — Convention

Keep the same frame, time basis, system boundary and sign convention throughout the substitution.

10 — Why this operation

Subtraction isolates a margin or difference between comparable states.

11 — Assumptions

Terms must share the same frame and unit.

12 — Independent check

Adding the margin back to the subtracted term should reconstruct the initial state.

13 — Numerical case

With $q_{\text{crop}} = 100 \text{ L/d}$, $\text{eta}_{\text{recovery}} = 0.95$ sans dimension: $q_{\text{makeup}} = 100 \times (1 - 0.95) = 5 \text{ L/day}$.

14 — Why the calculation works

Subtraction isolates a margin or difference between comparable states.

15 — Verification

Adding the margin back to the subtracted term should reconstruct the initial state.

16 — Mental estimate

Comparing the two terms predicts the sign before calculation.

17 — Interpretation

Size reserves for actual make-up and monitor any decline in recovery rate.

18 — What the result does not prove

The calculation proves neither that inputs are exact nor that the model remains valid outside the declared scenario; both require separate evidence.

19 — Sensitivity

The result moves directly when either term changes.

20 — Guided and autonomous exercises

Guided exercise. Recalculate this scenario: With $q_{\text{crop}} = 80 \text{ L/d}$, $\eta_{\text{recovery}} = 0.9$ sans dimension: $q_{\text{makeup}} = 80 \times (1 - 0.9)$?

Detailed guided correction — open after trying

With $q_{\text{crop}} = 80 \text{ L/d}$, $\eta_{\text{recovery}} = 0.9$ sans dimension: $q_{\text{makeup}} = 80 \times (1 - 0.9) = 8 \text{ L/day}$. The decision must then be checked against the module margins and assumptions.

Autonomous exercise. Recalculate this scenario: With $q_{\text{crop}} = 150 \text{ L/d}$, $\eta_{\text{recovery}} = 0.98$ sans dimension: $q_{\text{makeup}} = 150 \times (1 - 0.98)$?

Autonomous correction — open after trying

With $q_{\text{crop}} = 150 \text{ L/d}$, $\eta_{\text{recovery}} = 0.98$ sans dimension: $q_{\text{makeup}} = 150 \times (1 - 0.98) = 3 \text{ L/day}$. The decision must then be checked against the module margins and assumptions.

21 — Mission decision

Size reserves for actual make-up and monitor any decline in recovery rate.

Food output

$M_{\text{output}} = \text{yield_area} \times A_{\text{crop}}$

1 — Concrete question

What does " $M_{\text{output}} = \text{yield_area} \times A_{\text{crop}}$ " compute in "Food output"?

2 — Intuition without symbols

Area yield applied to crop area gives expected daily output.

3 — Quantities

M_{output} : daily output [kg/d]; yield_area : area yield [kg/(m²·d)]; A_{crop} : crop area [m²]

4 — Formula

$M_{\text{output}} = \text{yield_area} \times A_{\text{crop}}$

5 — Read aloud

Read " $M_{\text{output}} = \text{yield_area} \times A_{\text{crop}}$ " by naming every operation, subscript and grouping explicitly.

6 — Symbols and meaning

M_{output} : daily output [kg/d]; yield_area : area yield [kg/(m²·d)]; A_{crop} : crop area [m²]

7 — Pronunciation

Say subscripts, powers, parentheses and Greek letters explicitly so the relation can be reconstructed without seeing the page.

8 — Units

M_{output} [kg/d]; yield_area [kg/(m²·d)]; A_{crop} [m²]

9 — Convention

Keep the same frame, time basis, system boundary and sign convention throughout the substitution.

10 — Why this operation

Multiplication converts a rate, fraction or specific quantity into a total.

11 — Assumptions

Factors must belong to the same scenario and their units must combine correctly.

12 — Independent check

Dividing the result by a non-zero factor should recover the product of the others.

13 — Numerical case

With $\text{yield_area} = 0.5 \text{ kg/(m}^2\cdot\text{d)}$, $A_{\text{crop}} = 60 \text{ m}^2$: $M_{\text{output}} = 0.5 \times 60 = 30 \text{ kg/day}$.

14 — Why the calculation works

Multiplication converts a rate, fraction or specific quantity into a total.

15 — Verification

Dividing the result by a non-zero factor should recover the product of the others.

16 — Mental estimate

Estimating each factor separately quickly predicts product scale.

17 — Interpretation

Compare output with demand rather than only botanical performance of the best batch.

18 — What the result does not prove

The calculation proves neither that inputs are exact nor that the model remains valid outside the declared scenario; both require separate evidence.

19 — Sensitivity

A relative change in one factor transfers directly to the product when the others stay fixed.

20 — Guided and autonomous exercises

Guided exercise. Recalculate this scenario: With $\text{yield_area} = 0.4 \text{ kg}/(\text{m}^2 \cdot \text{d})$, $A_{\text{crop}} = 50 \text{ m}^2$: $M_{\text{output}} = 0.4 \times 50$?

Detailed guided correction — open after trying

With $\text{yield_area} = 0.4 \text{ kg}/(\text{m}^2 \cdot \text{d})$, $A_{\text{crop}} = 50 \text{ m}^2$: $M_{\text{output}} = 0.4 \times 50 = 20 \text{ kg/day}$. The decision must then be checked against the module margins and assumptions.

Autonomous exercise. Recalculate this scenario: With $\text{yield_area} = 0.75 \text{ kg}/(\text{m}^2 \cdot \text{d})$, $A_{\text{crop}} = 40 \text{ m}^2$: $M_{\text{output}} = 0.75 \times 40$?

Autonomous correction — open after trying

With $\text{yield_area} = 0.75 \text{ kg}/(\text{m}^2 \cdot \text{d})$, $A_{\text{crop}} = 40 \text{ m}^2$: $M_{\text{output}} = 0.75 \times 40 = 30 \text{ kg/day}$. The decision must then be checked against the module margins and assumptions.

21 — Mission decision

Compare output with demand rather than only botanical performance of the best batch.

Average crop-system power

$$P_{\text{avg}} = E_{\text{day}} / t_{\text{day}}$$

1 — Concrete question

What does " $P_{\text{avg}} = E_{\text{day}} / t_{\text{day}}$ " compute in "Average crop-system power"?

2 — Intuition without symbols

Daily energy can be converted to average power to compare the greenhouse with other settlement loads.

3 — Quantities

P_{avg} : average power [kW]; E_{day} : daily energy [kWh]; t_{day} : daily reference duration [h]

4 — Formula

$$P_{\text{avg}} = E_{\text{day}} / t_{\text{day}}$$

5 — Read aloud

Read " $P_{\text{avg}} = E_{\text{day}} / t_{\text{day}}$ " by naming every operation, subscript and grouping explicitly.

6 — Symbols and meaning

P_{avg} : average power [kW]; E_{day} : daily energy [kWh]; t_{day} : daily reference duration [h]

7 — Pronunciation

Say subscripts, powers, parentheses and Greek letters explicitly so the relation can be reconstructed without seeing the page.

8 — Units

P_{avg} [kW]; E_{day} [kWh]; t_{day} [h]

9 — Convention

Keep the same frame, time basis, system boundary and sign convention throughout the substitution.

10 — Why this operation

Division relates a quantity to a coherent capacity, duration or reference.

11 — Assumptions

Numerator and denominator must describe the same scenario and the denominator must remain positive.

12 — Independent check

Multiplying the result by the denominator should reconstruct the numerator.

13 — Numerical case

With $E_{\text{day}} = 240 \text{ kWh}$, $t_{\text{day}} = 24 \text{ h}$: $P_{\text{avg}} = 240 / 24 = 10 \text{ kW}$.

14 — Why the calculation works

Division relates a quantity to a coherent capacity, duration or reference.

15 — Verification

Multiplying the result by the denominator should reconstruct the numerator.

16 — Mental estimate

Comparing numerator and denominator scales predicts the result.

17 — Interpretation

Do not confuse average power with peak power when sizing electrical systems.

18 — What the result does not prove

The calculation proves neither that inputs are exact nor that the model remains valid outside the declared scenario; both require separate evidence.

19 — Sensitivity

The result rises with the numerator and falls as the denominator rises.

20 — Guided and autonomous exercises

Guided exercise. Recalculate this scenario: With $E_{\text{day}} = 360 \text{ kWh}$, $t_{\text{day}} = 24 \text{ h}$: $P_{\text{avg}} = 360 / 24$?

Detailed guided correction — open after trying

With $E_{\text{day}} = 360 \text{ kWh}$, $t_{\text{day}} = 24 \text{ h}$: $P_{\text{avg}} = 360 / 24 = 15 \text{ kW}$. The decision must then be checked against the module margins and assumptions.

Autonomous exercise. Recalculate this scenario: With $E_{\text{day}} = 120 \text{ kWh}$, $t_{\text{day}} = 24 \text{ h}$: $P_{\text{avg}} = 120 / 24$?

Autonomous correction — open after trying

With $E_{\text{day}} = 120 \text{ kWh}$, $t_{\text{day}} = 24 \text{ h}$: $P_{\text{avg}} = 120 / 24 = 5 \text{ kW}$. The decision must then be checked against the module margins and assumptions.

21 — Mission decision

Do not confuse average power with peak power when sizing electrical systems.

Food-production margin

$$M_{\text{food_margin}} = M_{\text{output}} - M_{\text{demand}}$$

1 — Concrete question

What does " $M_{\text{food_margin}} = M_{\text{output}} - M_{\text{demand}}$ " compute in "Food-production margin"?

2 — Intuition without symbols

The margin shows daily output remaining after demand is met.

3 — Quantities

$M_{\text{food_margin}}$: production margin [kg/d]; M_{output} : available output [kg/d]; M_{demand} : crew demand [kg/d]

4 — Formula

$$M_{\text{food_margin}} = M_{\text{output}} - M_{\text{demand}}$$

5 — Read aloud

Read " $M_{\text{food_margin}} = M_{\text{output}} - M_{\text{demand}}$ " by naming every operation, subscript and grouping explicitly.

6 — Symbols and meaning

$M_{\text{food_margin}}$: production margin [kg/d]; M_{output} : available output [kg/d]; M_{demand} : crew demand [kg/d]

7 — Pronunciation

Say subscripts, powers, parentheses and Greek letters explicitly so the relation can be reconstructed without seeing the page.

8 — Units

$M_{\text{food_margin}}$ [kg/d]; M_{output} [kg/d]; M_{demand} [kg/d]

9 — Convention

Keep the same frame, time basis, system boundary and sign convention throughout the substitution.

10 — Why this operation

Subtraction isolates a margin or difference between comparable states.

11 — Assumptions

Terms must share the same frame and unit.

12 — Independent check

Adding the margin back to the subtracted term should reconstruct the initial state.

13 — Numerical case

With $M_{\text{output}} = 35 \text{ kg/d}$, $M_{\text{demand}} = 30 \text{ kg/d}$: $M_{\text{food_margin}} = 35 - 30 = 5 \text{ kg/day}$.

14 — Why the calculation works

Subtraction isolates a margin or difference between comparable states.

15 — Verification

Adding the margin back to the subtracted term should reconstruct the initial state.

16 — Mental estimate

Comparing the two terms predicts the sign before calculation.

17 — Interpretation

A persistently negative margin requires rationing, imports or more capacity before reserves are depleted.

18 — What the result does not prove

The calculation proves neither that inputs are exact nor that the model remains valid outside the declared scenario; both require separate evidence.

19 — Sensitivity

The result moves directly when either term changes.

20 — Guided and autonomous exercises

Guided exercise. Recalculate this scenario: With $M_{\text{output}} = 18 \text{ kg/d}$, $M_{\text{demand}} = 20 \text{ kg/d}$: $M_{\text{food_margin}} = 18 - 20$?

Detailed guided correction — open after trying

With $M_{\text{output}} = 18 \text{ kg/d}$, $M_{\text{demand}} = 20 \text{ kg/d}$: $M_{\text{food_margin}} = 18 - 20 = -2 \text{ kg/day}$. The decision must then be checked against the module margins and assumptions.

Autonomous exercise. Recalculate this scenario: With $M_{\text{output}} = 50 \text{ kg/d}$, $M_{\text{demand}} = 42 \text{ kg/d}$: $M_{\text{food_margin}} = 50 - 42$?

Autonomous correction — open after trying

With $M_{\text{output}} = 50 \text{ kg/d}$, $M_{\text{demand}} = 42 \text{ kg/d}$: $M_{\text{food_margin}} = 50 - 42 = 8 \text{ kg/day}$. The decision must then be checked against the module margins and assumptions.

21 — Mission decision

A persistently negative margin requires rationing, imports or more capacity before reserves are depleted.

Starting question

What growing area is required to supply a declared daily edible mass when a crop produces a known edible yield per cycle?

Read aloud

Say: "area equals daily edible mass times crop-cycle duration divided by edible yield per square metre per cycle."

Symbols, pronunciation and meaning

A is growing area; m_{day} is edible mass demand per day; T is cycle duration; Y_{cycle} is edible yield per unit area for one cycle.

Units

If demand is kg/day, time is days, and yield is kg/m² per cycle, area emerges in square metres.

Origin and status of values

Demand must come from the food plan; cycle and yield should come from crop trials under comparable environment, not idealized catalogue claims.

Why this operation

Daily demand multiplied by cycle duration gives the food mass needed while one crop generation occupies the area.

Dividing by yield converts that mass to area.

Substitution and calculation

For 4 kg/day , $T = 30 \text{ days}$ and $Y = 6 \text{ kg/m}^2$: $A = 4 \times 30 / 6 = 20 \text{ m}^2$.

Calculator entry

Enter $4 \times 30 \div 6$. Keep the yield expressed for the same cycle definition used by T .

Mental estimate

The crew needs 120 kg over thirty days; at 6 kg per square metre, twenty square metres should produce that order of mass.

Independent check

Multiply 20 m^2 by $6 \text{ kg/m}^2 = 120 \text{ kg}$, then divide by 30 days to recover 4 kg/day .

Physical or operational interpretation

The area estimate feeds lighting, cooling, water circulation and chamber-volume budgets. A crop-area decision is therefore also an energy and thermal decision.

Plain-English translation

Under these assumptions, twenty square metres in continuous staggered production support four kilograms of edible crop per day.

Variation / sensitivity

A 20% yield loss would raise required area to 25 m² if the demand and cycle remain unchanged.

Limit / assumption

The formula assumes steady staggered cycles, consistent yield and no downtime between crops. Real systems need margin for germination failures, cleaning and disease control.

Formula 2 — lighting electrical energy per day

Starting question

How much electrical energy does a crop-lighting system consume each day at a declared power and photoperiod?

Read aloud

Read: “daily lighting energy equals lighting power times hours of operation.”

Symbols, pronunciation and meaning

P_{light} is electrical power drawn by the lighting system; t_{light} is the daily operating duration.

Units

Kilowatts multiplied by hours gives kilowatt-hours per day.

Origin and status of values

Use measured fixture input power, including drivers if they are inside the declared boundary, and the actual commanded photoperiod.

Why this operation

Energy is power integrated over time; for constant power, multiplication performs that integration directly.

Substitution and calculation

A 12 kW lighting array operating 16 h/day uses $12 \times 16 = 192$ kWh/day.

Calculator entry

Type 12×16 . Do not report 192 kW; the result is energy, kWh per day.

Mental estimate

Twelve kilowatts for about two thirds of a day should consume roughly 200 kWh, so 192 kWh is plausible.

Independent check

Divide 192 kWh by 16 h and recover the original 12 kW power.

Physical or operational interpretation

Lighting energy becomes habitat heat. Thermal control must eventually reject nearly all of the electrical energy unless some is exported in stored chemical energy or material.

Plain-English translation

The crop lights require 192 kilowatt-hours of electrical energy during each declared day.

Variation / sensitivity

Reducing photoperiod from 16 h to 14 h cuts energy by 25 kWh/day at the same power, but plant response may reduce yield; both sides of the trade must be tested.

Limit / assumption

Actual power may be dimmed or scheduled dynamically. This formula does not replace photon-flux or crop-response analysis.

Mission reasoning: make food production tolerant of biological failure

Stagger crops instead of betting on one harvest

If an entire staple crop is planted on the same day, a disease or control failure can remove a large fraction of future food at once. Staggered cohorts spread risk and smooth harvesting, processing and crew workload. They also make it easier to compare changes because adjacent cohorts provide reference conditions.

Separate seed security from production stock

Seed used for everyday planting should not exhaust the mission's genetic reserve. Protected seed lots, documented storage conditions and germination checks allow recovery after contamination or a failed generation. A crop system without viable backup seed can lose capability through a single biological event.

Close water loops carefully

Plants transpire large quantities of water, which can be recovered from cabin or growth-chamber humidity. Root-zone solution, condensate and hygiene systems may interact, but microbiological and chemical quality must be controlled. “Closed loop” does not mean every water stream can be mixed without treatment.

Treat lighting and cooling as one design problem

Electric light becomes heat. Raising photon delivery can improve growth only if the chamber can remove heat and maintain leaf temperature, humidity and carbon dioxide. Lighting upgrades that exceed cooling capacity can reduce crop performance while consuming more power.

Plan a safe mode for crop systems

During a settlement power emergency, agriculture may lose lighting before life support or medical loads. The crop plan should identify how long each chamber can tolerate reduced light, pumping or climate control, what can be harvested early, and which seed or mother plants receive priority. Agriculture needs load-shedding rules just like other infrastructure.

Crop-system exercises — connect food output to power, area and resilience

Exercise A — Area requirement

A crop contributes 3 kg of edible food per day. Its cycle is 40 days and tested edible yield is 8 kg/m² per cycle. Estimate continuous production area.

Reveal the reasoned solution

$A = 3 \times 40 / 8 = 15 \text{ m}^2$ under the simplified staggered-cycle assumption. Add operational margin for cleaning, failed plants and nonuniform performance before treating fifteen square metres as a design value.

Exercise B — Lighting energy

A chamber draws 9 kW of lighting power for 18 h/day. Calculate daily electrical energy.

Reveal the reasoned solution

$E = 9 \times 18 = 162 \text{ kWh/day}$. That energy also appears primarily as heat inside the controlled environment, so thermal rejection must be checked together with the electrical budget.

Exercise C — Lost cohort

Four equal crop cohorts support the food plan. One cohort is lost to disease. What immediate questions should mission planners ask?

Reveal the reasoned solution

Ask how much daily edible output is lost and for how long, whether stored food bridges the gap, whether another cohort can be accelerated safely, whether the disease threatens the remaining chambers, what seed is available, and whether resource allocation should change. The response is both biological and logistical.

Exercise D — Water-quality interface

Condensed water from the growth chamber is recovered. Why should it not automatically return directly to nutrient tanks?

Reveal the reasoned solution

Condensate may carry volatile compounds, microbes or cleaning residues. Its quality should be characterized and routed through an appropriate treatment and monitoring step. Closing a water loop requires controlled interfaces, not simply plumbing streams together.

Exercise E — Crop portfolio

Explain why a settlement might retain a lower-yield crop even when another crop produces more calories per square metre.

Reveal the reasoned solution

The lower-yield crop may provide vitamins, protein balance, culinary diversity, shorter emergency harvest, seed security or psychological value. Food-system optimization has multiple objectives; calories per square metre are important but not sufficient alone.

Exercise F — Reserve-food bridge

Stored food can cover a 12-person crew for 90 person-days beyond normal inventory. If one crop failure removes expected food for 15 days, how many crew-days does that event consume and is the reserve sufficient?

Reveal the reasoned solution

The event requires $12 \times 15 = 180$ person-days, so a 90 person-day reserve is insufficient by a factor of two. Either the reserve definition, alternative crop output or contingency ration plan must bridge the remaining gap.

Interactive beginner glossary

This vocabulary connects plant biology to the engineering quantities used to size a controlled food-production system.

- edible yield — Mass of harvested crop suitable for consumption, reported for a stated area, crop cycle or time period.
- biomass — Total mass of living or recently living plant material, including edible and non-edible fractions.
- harvest index — Fraction of total plant biomass represented by the desired harvestable product.
- crop cycle — Time from a defined planting or establishment point to the intended harvest stage.
- photoperiod — Number of hours per day during which plants receive the planned light period.
- PAR — Photosynthetically active radiation, the spectral range of light used most directly for photosynthesis.
- photon flux — Rate at which photons reach a surface, commonly used to describe useful plant-light delivery.
- canopy — The above-ground leaf and stem structure that intercepts light and exchanges gases with the atmosphere.
- transpiration — Movement of water through a plant followed by evaporation from leaves, which strongly affects humidity and water recovery.
- root zone — The environment surrounding plant roots, including water, nutrients, oxygen, temperature and microbial conditions.
- hydroponics — Cultivation in a nutrient solution without conventional soil, using various methods to support and aerate roots.
- nutrient solution — Water containing dissolved mineral nutrients supplied to plant roots under controlled concentration and chemistry.
- electrical conductivity — A measurement related to dissolved ionic concentration, often used as one indicator of nutrient-solution strength.
- pH — A logarithmic measure of acidity or alkalinity that affects nutrient availability and many chemical processes.
- germination — Early developmental process in which a viable seed resumes growth and establishes a seedling.
- seed bank — Protected collection of viable seed maintained to preserve crop capability, diversity or recovery after loss.
- cultivar — A cultivated plant variety selected for particular traits such as yield, growth habit, flavour or disease resistance.
- crop portfolio — Planned mixture of crops chosen to balance nutrition, yield, cycle time, resilience, labour and resource demand.
- staggered planting — Scheduling multiple crop cohorts at different ages so harvest and failure risk are distributed over time.
- integrated pest management — Layered prevention, monitoring and control of pests or disease using the least disruptive effective measures.
- quarantine — Separation of suspect plants, material or growth zones to reduce the chance of spreading disease or contamination.
- plant pathogen — A microorganism or other biological agent capable of causing disease in plants.
- crop failure reserve — Stored food, spare area, seed or schedule margin preserved to survive loss or delay of a harvest.
- controlled environment agriculture — Crop production in an engineered environment where light, temperature, humidity, gases and root conditions can be managed.
- food safety — Practices that reduce biological, chemical and physical hazards in produced, processed, stored and served food.
- post-harvest processing — Operations performed after harvest such as cleaning, drying, milling, cooking preparation or storage conditioning.
- inedible biomass — Plant material not intended for human consumption but potentially usable in recycling, composting or other processes.
- nutrient recovery — Capture and reuse of plant nutrients from waste or process streams after appropriate treatment and quality control.

- crop load shedding — Planned reduction of agricultural power or resource use during an infrastructure emergency while protecting recovery capability.
- germination test — Controlled test of a seed sample used to estimate viability before committing an important crop cycle.

Operational depth: run the growth chambers like critical infrastructure

Monitor trends, not isolated numbers

A single humidity or nutrient reading rarely tells the whole story. Operators should watch rate of change, spatial variation and relation between measurements. Slowly rising root-zone conductivity or declining germination can expose a developing problem before obvious crop loss occurs.

Use biological barriers between chambers

Separate air handling, tools, footwear procedures or quarantine zones can prevent one disease event from becoming a settlement-wide crop failure. Full isolation may be expensive, but some compartmentation is valuable precisely because the food system is biologically common-cause sensitive.

Budget crew labour honestly

Seeding, pruning, pollination support, harvesting, cleaning, food processing and maintenance all consume crew time. Highly productive crops can still be poor mission choices if their labour demand collides with EVA, maintenance or medical responsibilities. Automation should be evaluated against the tasks it truly removes.

Recycle nutrients with contamination awareness

Human waste and crop residues contain valuable nitrogen, phosphorus and other elements, but they also carry pathogens, salts, pharmaceuticals or unwanted chemicals. Nutrient recovery therefore requires treatment and monitoring. Circularity is a controlled process, not direct reuse of every waste stream.

Preserve culinary and psychological function

Fresh food changes more than calories. Smell, texture, variety and the act of tending living plants may contribute to morale and appetite in confinement. Those benefits should be acknowledged without using them to hide the engineering cost of area, power and labour.

Treat crop loss as an investigated anomaly

After a failed cohort, record environmental history, seed lot, nutrient batch, pathogen evidence, operator interventions and sensor calibration. Restarting immediately without understanding the failure can repeat it and consume the remaining reserve.

Use food inventory to buy biological recovery time

Stored food is not evidence that agriculture is unnecessary; it is the buffer that allows agriculture to fail safely. A settlement can use shelf-stable inventory to survive a missed planting, quarantine a chamber, clean a pathogen event or wait for a replacement pump without forcing the crew to harvest immature crops. The reserve duration should be linked to the longest credible biological recovery process, not only to nominal transit logistics. This makes food stock and crop-system resilience one combined design problem.

Keep atmosphere accounting visible

Plants consume carbon dioxide and release oxygen during net photosynthesis, then continue respiring in darkness. A large crop area can therefore affect habitat gas control, especially if chambers share atmosphere with crew spaces. The ECLSS design should know when crop lights switch, what gas exchange is expected and how rapidly control valves or scrubbers can respond. Agriculture can support atmospheric loops, but it should never be treated as an unmeasured substitute for engineered life-support control.

Make crop cleaning a planned production phase

After harvest, channels, trays, sensors and root-zone equipment may need cleaning or disinfection before the next cohort. If this downtime is omitted from the area calculation, real production falls below the design value even when biological yield is perfect.

Cleaning also consumes water, chemicals and crew time. A mature crop schedule therefore includes turnaround between cycles and records whether sanitation methods themselves affect materials, microbes or the next planting.

Plan pollination, reproduction and crop renewal as real operations

Some crops self-pollinate easily, while others may need airflow, mechanical assistance or deliberate handling. Seed production can also compete with edible harvest because plants kept for reproduction occupy chamber area longer than crops harvested early. A settlement that wants long-term agricultural continuity must therefore plan how varieties are renewed, how seed quality is checked and how accidental mixing is prevented. Those tasks belong in the production schedule and labour budget. If every crop cycle consumes imported seed, the system may produce food efficiently while still depending on a fragile external biological supply chain.

Track food-system reserve as days of safe diet

A crop chamber can look healthy while the settlement's nutritional reserve is shrinking because one staple is behind schedule or stored food has been consumed faster than planned. Operators should therefore translate inventory and expected harvests into days of acceptable diet under conservative assumptions. This creates an early warning before the problem becomes visible on a plate. The calculation should include crop uncertainty, processing losses and the possibility that a chamber must be quarantined rather than assuming every scheduled harvest arrives on time.

Operational review checklist

- Size crop area from edible output, cycle time and tested yield rather than total biomass.
- Maintain a crop portfolio with different nutritional and resilience roles.
- Protect backup seed separately from routine planting inventory.
- Stagger plantings to distribute harvest and biological failure risk.
- Couple lighting power decisions to chamber cooling and humidity control.
- Monitor root-zone chemistry and water quality with calibrated instruments.
- Keep disease-control barriers and quarantine procedures between crop zones where practical.
- Calculate stored-food and spare-capacity margin for a lost crop cycle.
- Include labour for cleaning, harvesting and processing in agriculture planning.
- Investigate crop failures before restarting the same conditions.

Primary sources and bridges

- [NASA Science — Space Crops](#)
- [NASA Science — Advanced Plant Habitat](#)
- [NASA NTRS — Bioregenerative Life Support for Humans in Space](#)

FR ↔ EN parity matrix

Required crop area	Surface de culture nécessaire
Daily lighting energy	Énergie quotidienne d'éclairage
Crop-water make-up	Appoint d'eau de culture
Food output	Production alimentaire
Average crop-system power	Puissance moyenne du système de culture
Food-production margin	Marge alimentaire