

Feed the Field, Keep the Pond: Choosing a Fertilizer Plan

Investigation question: Which of five fertilizer plans best meets the garden club's criteria for crop yield and pond health while staying inside its budget and labor limits, and what trade-off does the best plan still accept?

Data-driven decision

Groups of 4

1 session

Setup 5 · Activity 45 · Cleanup 3 min

MS-ETS1-2 · assesses

MS-LS2-3 · practice

MS-LS2-4 · supports

Scientific purpose

Students take the role of a school garden club whose field drains into a pond that turned green last spring. They receive a simulated three-year dataset comparing five fertilizer plans on yield, pond nitrate, dawn oxygen, algae cover, cost and labor, and they evaluate the plans with a systematic process: hard constraints as pass or fail, then weighted scores on the criteria. The data were built so that no plan wins outright, which forces students to name the trade-off they accept and to use the nitrogen cycle to explain why timing and buffer strips change what reaches the pond.

Why this helps students with this chapter

The pond phenomenon asks why more fertilizer in the field means dead fish in the pond. Explaining it is one skill; deciding what to do about it is another, and that decision is where criteria, constraints and a cycle model have to work together. Students see that 'use less fertilizer' is not automatically the answer, that timing and a strip of grass change what reaches the water, and that a systematic matrix makes a disagreement about weights visible instead of hidden.

Standards connections

MS-ETS1-2 (assesses, evaluating competing design solutions with a systematic process against criteria and constraints): Students score five competing plans in a decision matrix, apply constraints as pass or fail, weight the criteria, rank the plans and justify a recommendation that names the criterion it falls short on. The matrix and the written recommendation are direct evidence for this PE.

MS-LS2-3 (practice, using a model of nitrogen cycling to explain the data): Students trace fertilizer nitrogen from the bag through soil, runoff, pond, algae and decomposers to explain why nitrate and oxygen move together in the data; the cycle model is used, not built, so the role is practice.

MS-LS2-4 (supports, the link between a changed physical component (nutrient load) and a population (fish, algae)): The dataset shows algae rising and dawn oxygen falling as pond nitrate rises; students read that pattern as background to the decision rather than constructing a full argument about population change.

Roles (rotate each session)

- **Data reader:** Reads each plan's numbers aloud from the dataset and checks every entry the group writes in the matrix against the table.
- **Matrix keeper:** Fills in the pass/fail matrix and the weighted-score table, and does the arithmetic with a second group member checking.
- **Cycle tracer:** Keeps the nitrogen-cycle map in view and explains, for each plan, which arrow the plan changes (amount applied, timing, runoff path).
- **Spokesperson:** Drafts the group's recommendation and the trade-off sentence, and presents it to the class in the debrief.

Materials

Item	Quantity	Per	Note
Recording sheet with the dataset, matrix and questions	1	student	
Calculator	1	group	
Printed nitrogen-cycle map from the presentation (or W4)	1	group	
Highlighters in two colors (pass, fail)	2	group	
Chart paper and marker for the class ranking	1 sheet	class	

Estimated cost: 0 to 3 per class (an estimate; Printing only; calculators and highlighters are classroom stock.)

Safety

- Paper-and-pencil activity; no hazards beyond ordinary classroom use.
- If the optional fertilizer jar is used, only the teacher handles the fertilizer, the jar is labeled and kept away from food, and hands are washed afterward.

Teacher preparation and setup

1. Print the recording sheet and read the dataset yourself so you can answer questions about what each column measures (nitrate as nitrogen in milligrams per liter; dawn oxygen in milligrams per liter; yield in kilograms per plot).
2. Decide whether groups use the default weights (yield 3, nitrate 3, oxygen 2, cost 1, labor 1) or set their own; if they set their own, require a one-sentence reason per weight before scoring.
3. Draw the class ranking chart with five plan rows and a column per group so disagreements show at a glance.
4. Optional: set up a jar of pond or aquarium water with a pinch of houseplant fertilizer in a sunny window a week ahead as a live illustration of algae responding to nutrients (teacher handles the fertilizer).

Investigation design

Independent variable	The fertilizer plan (A through E): amount applied, timing, and whether a grass buffer strip stands between the field and the pond
Dependent variable	Crop yield, pond nitrate after spring storms, dawn dissolved oxygen in midsummer, algae cover, cost and labor, as given in the simulated dataset
Controlled	Same plot size (100 square meters) and crop for every plan; Same pond and the same three years of weather; Same measurement methods and dates; Same scoring rules and weights applied to every plan
Trials	The simulated dataset is presented as three-year averages with a wet-year and a dry-year value for nitrate, so that students see weather as a source of variation.
Comparison	Plan A (no fertilizer) is the reference; B through E are the competing solutions.

Student procedure

1. Read the scenario and the dataset. In your group, say in one sentence what each column measures and which direction is 'good' for the pond and which for the field. Note that the nitrate and oxygen values are for the wet year unless the column says otherwise.
2. Copy the criteria and constraints from the scenario into the top of the matrix. Decide as a group which items are constraints (hard limits that a plan either meets or does not) and which are criteria (goals that can be met more or less well).
3. Fill in the pass/fail matrix: for every plan and every criterion or constraint, write pass or fail using the wet-year numbers for the pond. Highlight fails.
4. Fill in the weighted-score table: give each plan 2 points on a criterion it meets, 1 point if it misses by 10 percent or less, and 0 if it misses by more. Multiply by the weight and add across to get a total for each plan.
5. Rank the plans by total. Then apply the constraints as a filter: any plan that fails a constraint cannot be chosen as it stands, whatever its score. Write which plans survive.
6. Use the nitrogen-cycle map to explain, for plans B, C and D, which arrow of the cycle each plan changes and why that changes the pond nitrate in the data.
7. Write the group's recommendation: the plan you choose, the criterion it falls short on, and what you would change (a weight, a constraint or a combination of plans) to do better. Record the trade-off in one sentence that starts 'We accept...'.
8. Report your ranking to the class chart. Compare with other groups; where rankings differ, find the weight or the pass/fail call that caused it.
9. Answer the analysis questions on your own.

Expected observations

- Pass/fail: A fails yield; B fails nitrate and oxygen; C fails oxygen (4.5 versus 5.0); D fails the cost constraint (95 versus 80); E fails yield (68 versus 70). No plan passes everything.

- Weighted totals with the default weights: A 14, B 10, C 18, D 18, E 17. C and D tie; the constraint filter removes D, leaving C first and E second among surviving plans.
- Groups that raise the oxygen weight or score D's cost as 'close' will rank D first, and groups that weight the pond more heavily than the field will choose E; these disagreements are the material for the debrief.

Likely difficulties

- Students apply the 10-percent rule inconsistently. Work one example on the board: 10 percent of 70 kg is 7 kg, so a yield from 63 to 69.9 earns 1 point; 10 percent of \$80 is \$8, so \$95 earns 0.
- Students treat the constraints as just two more criteria and let D win on score. Insist on the filter step: a plan over budget cannot be chosen as it stands, though the club could decide to change the budget, which is a different decision.
- Students read the dry-year column and conclude B is fine. Ask why the club should plan for the wet year (the storm is what caused last spring's bloom).
- The nitrogen trace in q5 often stops at 'the grass absorbs it.' Push for the second mechanism (slowing the water so soil holds the nitrate and bacteria act on it) and for the timing mechanism in plan C.

Structured debrief

1. Put every group's ranking on the chart. Most groups will have C and D at the top with E close behind; ask what separates them. C misses the oxygen criterion by a hair, D breaks the budget, E misses the yield target by 2 kg. There is no clean winner, and that is normal in engineering: the matrix shows exactly which criterion each plan trades away.
2. Ask which decisions in the process were judgments rather than data: the weights, the 10-percent rule for partial credit, and the choice to score the wet year. Change one weight on the board (for example oxygen from 2 to 3) and watch the ranking shift. A systematic process does not remove judgment; it makes the judgment visible so it can be argued about.
3. Trace the nitrogen with the cycle map: the bag holds fixed nitrogen; soil bacteria turn ammonium forms into nitrate, which dissolves and travels with runoff; a split dose means less nitrate sits in the soil when the spring storms come, and the plants take up the second dose while they are growing fast; a buffer strip slows the water so the soil holds it, its plants absorb nitrate, and denitrifying bacteria in the wet strip send some nitrogen back to the air. The pond gets what is left.
4. Close with the phenomenon: the fish died from low oxygen, not from fertilizer in the water. The dawn-oxygen column is the one that tracks the fish, and it is the one students should name in q8.

Recording sheet: what students fill in

Lab 3 recording sheet: Feed the field, keep the pond

Scenario. Your garden club grows vegetables on a sloping field above the school pond. Last spring the pond turned green after a storm and several fish died. The club wants a fertilizer plan for next year. A university extension office ran a three-year trial of five plans on plots like yours, with a pond downhill of each plot. The

numbers below are a teaching dataset: they were invented for this activity, but the patterns follow what field trials of fertilizer timing and buffer strips find.

Criteria and constraints set by the club — Criteria (goals): yield of at least 70 kg per plot; wet-year pond nitrate of 10 mg/L or less (the U.S. drinking-water limit for nitrate measured as nitrogen, used here as the pond target); dawn oxygen in midsummer of at least 5 mg/L (below this, many fish are stressed).
Constraints (hard limits): cost of \$80 or less per season; labor of 6 hours or less per season.

Three-year trial of five fertilizer plans (per 100 square meter plot; pond measured downhill of each plot)

Simulated teaching dataset: the numbers are invented to be realistic, not measured.

Plan	Nitrogen applied (kg per plot per season)	Average yield (kg)	Pond nitrate after spring storms, wet year (mg/L as N)	Pond nitrate, dry year (mg/L as N)	Algae cover in mid-July (%)	Dawn oxygen in mid-July (mg/L)	Cost per season (\$)	Labor per season (hours)
A: no fertilizer	0	42	1.5	1.0	5	7.5	0	2
B: one full dose in early spring	2.0	78	18.0	7.0	60	2.5	60	3
C: full dose split into two half doses (spring and early summer)	2.0	80	9.0	4.0	30	4.5	60	5
D: one full dose plus a 10 m grass buffer strip above the pond	2.0	72	4.0	2.0	12	6.5	95	6
E: one half dose plus the grass buffer strip	1.0	68	3.0	1.5	8	7.0	65	6

Simulated teaching dataset. Nitrate is reported as nitrogen. Dawn oxygen is the lowest point of the day, after a night with no photosynthesis.

Pass/fail matrix (use wet-year nitrate)

Plan	Yield at least 70 kg	Wet-year nitrate 10 mg/L or less	Dawn oxygen at least 5 mg/L	Cost \$80 or less (constraint)	Labor 6 h or less (constraint)	Survives the constraints?
A						
B						
C						
D						
E						

Weighted-score table (2 = meets, 1 = misses by 10 percent or less, 0 = misses by more; multiply by the weight)

Plan	Yield (weight 3)	Nitrate (weight 3)	Oxygen (weight 2)	Cost (weight 1)	Labor (weight 1)	Total	Rank
A							
B							
C							
D							
E							

Which arrow of the nitrogen cycle does each plan change?

Plan	What the plan changes (amount, timing, path of runoff)	Why the pond nitrate changes, using the cycle
B		
C		
D		
E		

1. Group recommendation: which plan do you choose, which criterion does it fall short on, and what would you change to do better? Finish with one sentence that starts 'We accept...'.

Answer: Most defensible: plan C (split dose). It survives both constraints and meets yield (80 kg) and nitrate (9.0 mg/L) but misses dawn oxygen by 0.5 mg/L (4.5 versus 5). Improvement: add a narrow buffer strip, or move the second half dose later, to push nitrate and algae down further. Trade-off sentence, for example: 'We accept a midsummer dawn oxygen that is slightly below the fish target in a wet year in exchange for full yield within budget.' Also acceptable: plan E, which keeps the pond healthiest (3.0 mg/L, 7.0 mg/L oxygen) and misses yield by 2 kg, with the trade-off 'We accept about 3 percent less crop to keep the pond safe.' Plan D is acceptable only if the group explicitly proposes raising the budget, since it fails a constraint.

Why: Full credit is for a surviving plan, the named shortfall with its number, a specific improvement, and an honest trade-off; the choice between C and E depends on weights, which the student must state.

- Chooses a plan that passes both constraints, or explicitly proposes changing a constraint
- Names the missed criterion with the number
- Proposes a specific change
- Writes a 'We accept...' sentence that matches the data

2. Another group ranked a different plan first. Name one weight or one pass/fail call that could explain the difference.

Answer: Examples: a group that weighted oxygen 3 instead of 2 would lift E into a tie with C (both 19) and put D at 20 before the constraint filter, so E could be ranked first on a pond-first argument; a group that scored D's \$95 as 'close' (1 point) would put D alone at the top with 19; a group that used dry-year nitrate would pass B on nitrate (7.0) and raise its score from 10 to 16.

Why: Any single weight or scoring call that changes the ranking earns credit; the point is that disagreements come from visible choices in the process.

- Names one specific weight or pass/fail decision
- Explains the direction it would move the ranking

Analysis questions: answer key

3. Compute the weighted total for plan C and for plan D, showing each criterion's points times its weight. Which plans tie or come close, and what breaks the tie?

Answer: Plan C: yield $2 \times 3 = 6$; nitrate $2 \times 3 = 6$; oxygen $1 \times 2 = 2$ (4.5 is within 10 percent of 5); cost $2 \times 1 = 2$; labor $2 \times 1 = 2$; total 18. Plan D: yield $2 \times 3 = 6$; nitrate $2 \times 3 = 6$; oxygen $2 \times 2 = 4$; cost $0 \times 1 = 0$ (\$95 is more than 10 percent over \$80); labor $2 \times 1 = 2$; total 18. C and D tie at 18, with E at 17. The tie is broken by the constraint filter: D fails the \$80 budget, so C ranks first among plans the club can actually choose.

Why: Check each product and the 10-percent calls (oxygen threshold 4.5, cost threshold \$88). The tie is deliberate.

Also acceptable: If the student used different weights, grade the arithmetic against those weights and require the tie-break to use the constraints.

4. By what percentage does splitting the dose (plan C) reduce wet-year pond nitrate compared with the single dose (plan B)? Show the calculation. Then do the same for the buffer strip (plan D versus plan B).

Answer: C versus B: $(18.0 - 9.0) \div 18.0 = 0.50$, a 50 percent reduction. D versus B: $(18.0 - 4.0) \div 18.0 = 0.78$, about a 78 percent reduction.

Why: Percent change relative to the single-dose value. Both plans apply the same nitrogen, so the reductions are due to timing and the buffer alone.

Also acceptable: Accept 77.8 percent or 'about three quarters'.

5. Plans B, C and D all apply the same 2.0 kg of nitrogen, yet their pond nitrate values differ. Use the nitrogen cycle to explain what happens to the nitrogen that does not reach the pond in plans C and D.

Answer: Plan C: half the nitrogen is in the soil when the spring storms come, so there is less nitrate to wash off; the second half is applied when the crop is growing fast and absorbs it quickly, building it into plant proteins (the producers reservoir) instead of leaving it in the soil water. Plan D: the grass strip slows the runoff so more water soaks into the soil instead of racing to the pond; the strip's plants absorb nitrate through their roots; and in the wet soil of the strip, denitrifying bacteria convert some nitrate back to nitrogen gas that returns to the air. In both plans the nitrogen is not destroyed: it ends up in crop and grass tissue, in soil, or back in the atmosphere instead of in the pond.

Why: The student must use the cycle's reservoirs and processes (uptake into producers, soil storage, denitrification to the air) and must not say the nitrogen disappears.

- Explains plan C by timing and plant uptake
- Explains plan D by slowed runoff plus uptake and/or denitrification
- States where the nitrogen went instead of the pond, with no matter destroyed

6. Compare yield per dollar for plans B, C, D and E. Which plan gives the most crop for the money, and why might the club still not choose it?

Answer: B: $78 \div 60 = 1.30$ kg per dollar; C: $80 \div 60 = 1.33$ kg per dollar; D: $72 \div 95 = 0.76$ kg per dollar; E: $68 \div 65 = 1.05$ kg per dollar. Plan C gives the most crop per dollar. The club might still hesitate because C's dawn oxygen (4.5 mg/L) is below the fish target in a wet year, and because its two applications take 5 hours of labor; a club that values the pond above yield would pick E despite the lower ratio.

Why: Simple ratios, then a reason grounded in the criteria the ratio ignores.

Also acceptable: Accept rounding to one decimal place.

7. Explain the pattern across the plans between pond nitrate, algae cover and dawn oxygen. Why is oxygen lowest at dawn, and which living things are using it up?

Answer: As pond nitrate rises from A to B, algae cover rises (5 to 60 percent) and dawn oxygen falls (7.5 to 2.5 mg/L); C, D and E sit in between in the same order. Nitrate (with phosphorus) feeds the algae, which multiply into a bloom. When the bloom dies, decomposers (bacteria and fungi) feed on it and respire, using dissolved oxygen. Oxygen is lowest at dawn because photosynthesis by the living algae adds oxygen only in daylight, while cellular respiration by the decomposers, the algae themselves and the fish runs all night; by dawn the night's use has drawn the level down. The fish are not poisoned by nitrate at these levels; they suffocate.

Why: Full credit needs the pattern in the numbers, the nutrient-to-algae link, decomposers' respiration as the oxygen sink, and the day-night reason for the dawn minimum.

- Describes the pattern with numbers from the data
- Links nitrate to algae growth
- Identifies decomposers' (and other organisms') cellular respiration as the oxygen sink
- Explains the dawn minimum by night without photosynthesis

8. The club can only afford to measure one thing in its own pond next summer. Which column of the dataset would you measure, and why is it the best single warning sign for the fish?

Answer: Dawn dissolved oxygen. It is the quantity that directly determines whether fish can breathe, it combines the effects of nutrients, algae and decomposition into one number, and it is lowest at the one time of day when the danger is greatest. Nitrate is a cause further upstream and can be high before any harm shows; algae cover is visible but does not say how much oxygen the pond has left.

Why: Students should choose the measurement closest to the harm. Accept nitrate with a strong argument that it gives earlier warning, but the best answer is oxygen.

- Names dawn oxygen (or defends nitrate as an early warning)
- Explains why it is the best single indicator for fish

9. Propose a plan F that combines features of C and E, estimate its values for yield, wet-year nitrate, cost and labor from the data, and say whether it would pass all the criteria and constraints.

Answer: Plan F: a half dose split into two quarter doses, plus the buffer strip (combining C's timing with E's amount and strip). Estimates from the data: yield about 68 to 72 kg (E's 68 lifted a little by better timing, as C beat B by 2 kg); wet-year nitrate about 2 mg/L (below E's 3.0, since splitting halved nitrate for the full dose); cost about \$65 (same materials as E); labor about 8 hours (E's 6 plus a second application, which added 2 hours in C). Result: F likely passes yield (if about 70), nitrate, oxygen and cost, but fails the 6-hour labor constraint; the club would have to accept the extra labor or recruit volunteers. Alternative F: full split dose plus buffer, estimated yield about 74 to 76, nitrate about 2 to 3, cost about \$95 (fails budget), labor 8 (fails).

Why: Any sensible combination with estimates that follow the direction of the data earns credit; the student must check every criterion and constraint and name the one that fails.

- Combines features from C and E (or others) explicitly
- Estimates each required value with reasoning from the data
- Checks the estimates against every criterion and constraint and names any failure

Individual evidence of learning

Each student submits a completed pass/fail matrix, weighted-score table, cycle-arrow table and written answers to q1 through q9. The matrix, the ranking and q1 are the direct evidence for evaluating competing

solutions systematically; q5 and q7 are the evidence for using the nitrogen cycle and the oxygen link to explain the data.

Assessment criteria

Criterion	Proficient looks like
Systematic evaluation	Every cell of the pass/fail matrix and weighted-score table is filled correctly from the data; constraints are applied as a filter after scoring; totals and ranks are right for the weights used.
Justified recommendation	Names a surviving plan, states the criterion it misses with the number, proposes a specific improvement, and writes an honest 'We accept...' trade-off sentence.
Cycle reasoning	Explains plan C by timing (less nitrate in the soil when storms come, more taken up by growing plants) and plan D by the buffer (slower runoff, uptake by strip plants, denitrification), with nitrate named as the form that travels.
Reading the pond data	Explains that high nitrate feeds algae, dead algae feed decomposers, and decomposers' respiration drives dawn oxygen down; identifies dawn oxygen as the best warning sign for fish.

Accessibility adaptations

- Provide the dataset in large print and as a read-aloud; the data reader role already voices every number.
- Supply the matrix with plan A already scored as a worked row, and a strip showing the 10-percent thresholds for each criterion (63 kg, 11 mg/L, 4.5 mg/L, \$88, 6.6 h).
- Allow the cycle-arrow table to be completed by drawing arrows on a printed nitrogen-cycle map and photographing it.
- Accept q1, q5 and q7 as a recorded spoken response, and let the spokesperson role rotate so that presenting is optional.

Low-cost alternative

The lab is already paper only. If calculators are scarce, give the weighted-score table with the multiplication done and have students fill in only the points and the totals, or run the scoring as a whole-class activity on the board with groups calling out each cell.

Model limitations

The dataset is invented. Its patterns (split doses and buffer strips lowering nitrate in runoff; nitrate feeding algae; decomposition of a bloom lowering dawn oxygen) follow what field studies find, but the sizes of the effects, the costs and the labor are teaching numbers, and a real pond would also respond strongly to phosphorus, which the dataset leaves out. The 10 mg/L nitrate value is a drinking-water standard, not a pond-health standard; it is used here as a simple target. The decision process is also simplified: real projects revisit criteria and constraints after the first evaluation, which plan F in q9 begins to do. This activity has not been physically tested by the authors.

Teacher notes

Grade the matrix against the thresholds (10 percent of each target: 7 kg, 1 mg/L, 0.5 mg/L, \$8, 0.6 h) rather than against a single right ranking; a group with different weights can be fully correct if its arithmetic and its filter step are right. The C-D tie and E's near miss are deliberate. If a group insists on D, ask them to write the budget change as a formal decision the club must make, which is good engineering practice. Save the class chart for W9, which asks students to transfer the same process to a new problem.