**Abstract**

Like many perennial crops, coffee exhibits alternate bearing, a pattern of reproduction in which high-yielding years are followed by low-yielding ones. Alternate bearing threatens farmer livelihoods, yet little is known about the underlying mechanisms in coffee or the potential for farm management to mitigate it. The resource budget model, an ecological theory positing endogenous resource tradeoffs as the driver of reproductive variability, could help fill this gap. On three coffee farms in Santa María de Dota, Costa Rica, we manipulated relative fruit load, fertilizer levels, and shade cover to test whether the model’s core assumptions (i.e., that fruiting depletes resources and limits investment in subsequent reproduction) can elucidate patterns of alternate bearing in coffee, and to assess whether these patterns are impacted by farm management practices. Coffee plants exhibited within-year and between-year tradeoffs of a high fruit load that scaled from decreased bean size during the same season to fewer fruited nodes and fruits per node in both old and new cohorts of branches during the subsequent season. Stem nitrogen concentration was also depleted in response to high fruit loads and recovered during the subsequent season of low fruiting. The findings provide novel evidence that tradeoffs of a high fruit load are manifested in several reproductive traits at both the branch- and plant-level and offer initial support for the resource budget model in the system. While both moderate shade and increased fertilizer levels tended to improve reproductive traits, a lack of interactive effects between either management treatment and the relative fruit load treatment suggests that they do little to mitigate the reproductive tradeoffs underlying alternate bearing.

**Keywords**

Biennial bearing, *Coffea arabica*, Resource budget model, Yield, Shade coffee, Fertilizer

Key to variables in “manip\_e1i\_e2f\_e2i\_e2h.csv” and “cleandat\_n1i\_n1h.csv” datasets.

* branch\_id: unique ID for each branch. 4 branches per plant.
* plant\_id: unique ID for each plant.
* plant\_num: plant number 1-88, repeats for each farm.
* orientation: branch orientation. NSEW.
* farmer: farmer ID.
* plot\_id: unique ID for each fertilizer \* light treatment plot - 12 per farm.
* plot\_type: combined fertilizer and light treatment description: hshd = high fertilizer, shaded. lshd - low fertilizer, shaded. hsun = high fertilizer, sun. lsun = low fertilizer, sun.
* fert\_trt: fertilizer treatment. h = high. l = low.
* shd\_trt: shade (light) treatment. shd = shaded. sun = sun-grown.
* per\_thin: percent thinning treatment. 0 = 0% thinned; 33 = 33% thinned. 66 = 66% thinned. This treatment is referred to in the manuscript as relative fruit load (RFL), in which case 0% thinned = 100% relative fruit load, 33% thinned = 66% RFL, 66% thinned = 33% RFL.
* Key to branch measurements:
  + Before the underscore:
    - First symbol indicates year in which the branch was selected: e = twenty-eighteen (2018); n = twenty-nineteen (2019).
    - Second symbol indicates the branch’s reproductive year in which the measurement was taken. 1 is in the plant’s first year of reproduction, 2 is the branch’s second year of reproduction. Only applies to 2018 branches which were followed for 2 reproductive cycles.
    - Third symbol indicates the reproductive stage at which the measurement was taken: i = fruit initation; h = fruit harvest/maturity; f = flowering.
    - Example: e1i = 2018 branch in 1st year of reproduction (2018) at fruit initiation.
  + After the underscore:
    - The symbols after the underscore indicate the measurement that was taken:
      * len = length (cm)
      * tot\_nod = total nodes on the branch.
      * pot\_nod = nodes with reproductive potential (not newly extended ones). Note that this measurement was only taken at the first measurement point at experiment establishment (e1i) – after which, this measurement was replaced with the actual number of reproductive nodes (see flor\_nod, frt\_nod).
      * pre\_frt = fruits per branch prior to fruit load manipulation. (only applies to baseline measurements.)
      * post\_frt = fruits per branch prior after fruit load manipulation. (only applies to baseline measurements.)
      * tot\_lvs = total leaves per branch.
      * frt\_nod = fruited nodes.
      * flor\_nod = flowering nodes.
      * buds = floral buds on the branch.
      * tot\_frt = total fruit on the branch.

Key to variables in “bean-qual-18.csv” dataset.

* sample\_id: unique sample identifier.
* farmer: farmer ID.
* shd: shade (light) treatment. shade = shaded. sun = sun-grown.
* fert: fertilizer treatment. high; low.
* thinning: percent thinning. see per\_thin above.
* bean\_id: unique bean identifier.
* bn\_weight: bean weight.
* bn\_diam: bean diameter.
* plot\_type: describes the combined fertilizer and light treatments.
* plot\_thin: describes the combined fertilizer, light, and thinning treatments.

Key to variables in resource datasets: “Resource\_analysis…”

* tissue: tissue type. leaf; stem.
* plant\_id: unique plant identifier.
* per\_thin, fert\_trt, shd\_trt, plot\_type: see above.
* per\_n: percent nitrogen.
* per\_c: percent carbon.
* c\_n: carbon to nitrogen ratio.