Nitrogen Scavenging

# How to Maximize Cover Crop Benefits and Credits in Ag. Order 4.0 and Beyond

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Long-term research is important !!!

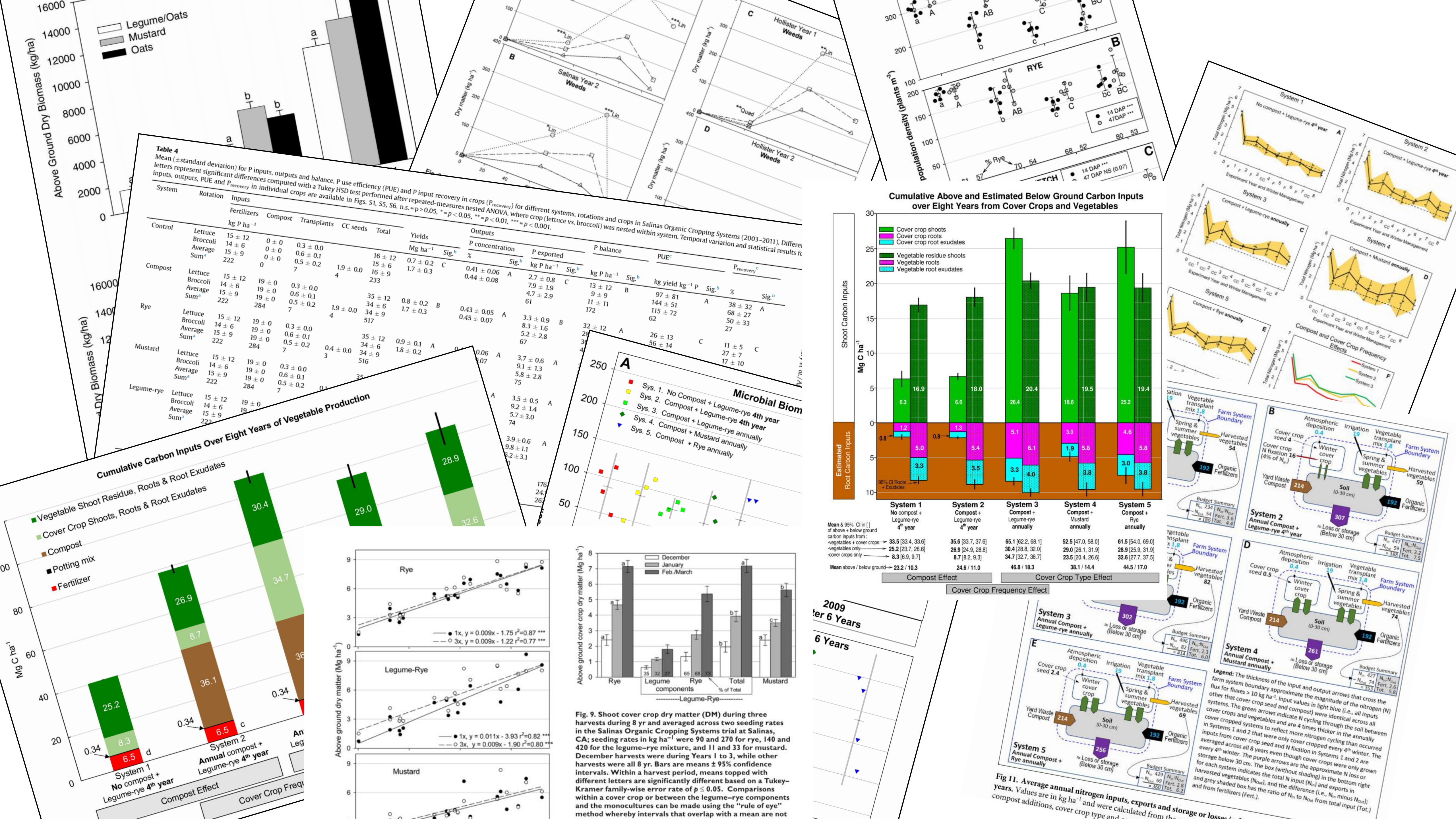


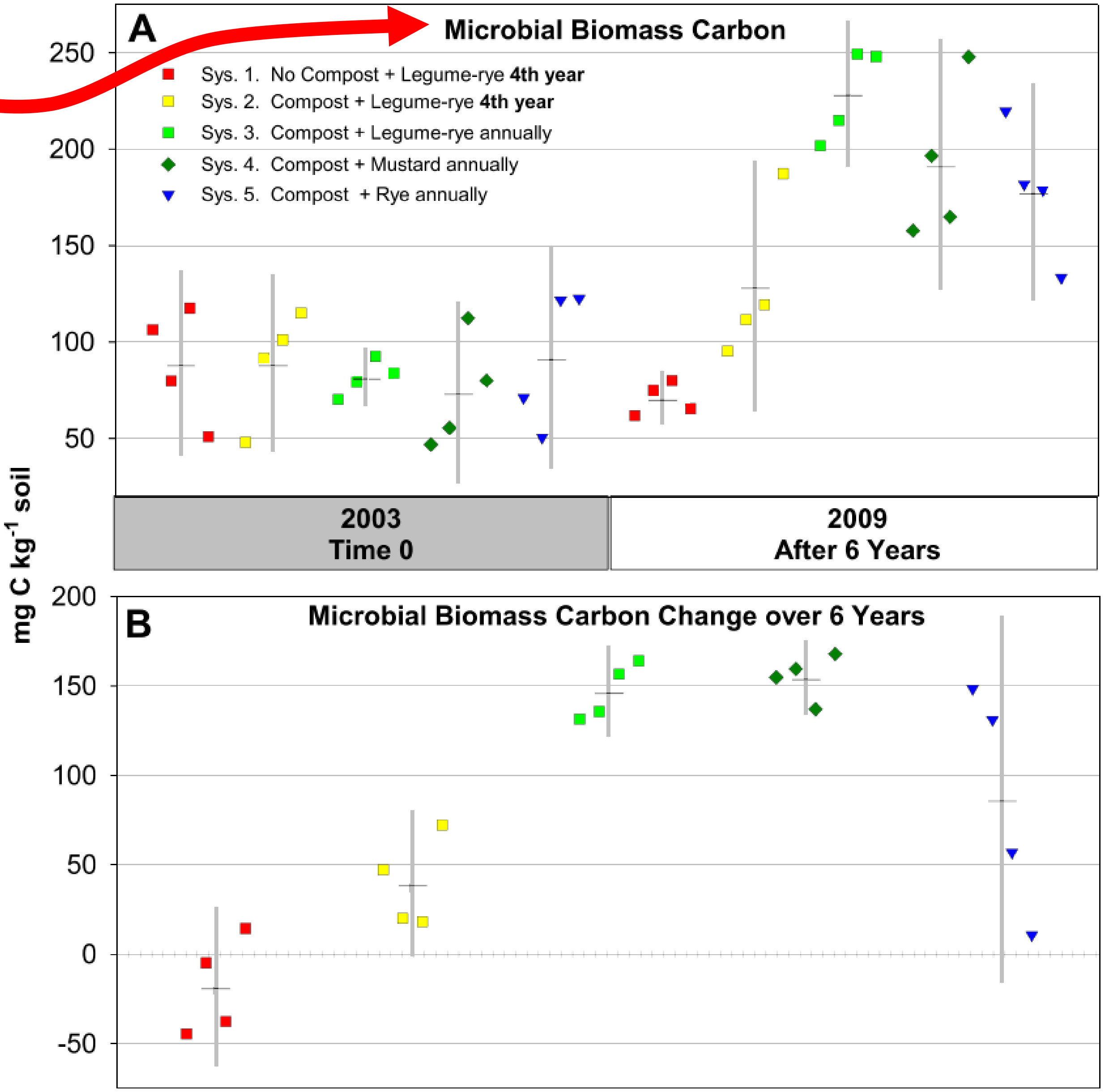
**Table 4**
Mean (±standard deviation) for P inputs, outputs and balance, P use efficiency (PUE) and P input recovery in crops ($P_{recovery}$) for different systems, rotations and crops in Salinas Organic Cropping Systems (2003–2011). Differe letters represent significant differences computed with a Tukey HSD test performed after repeated-measures nested ANOVA, where crop (lettuce vs. broccoli) was nested within system. Temporal variation and statistical results fo inputs, outputs, PUE and $P_{recovery}$ in individual crops are available in Figs. S1, S5, S6. n.s. = $p > 0.05$, * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$.

**Fig. 9. Shoot cover crop dry matter (DM) during three harvests during 8 yr and averaged across two seeding rates in the Salinas Organic Cropping Systems trial at Salinas, CA; seeding rates in kg ha$^{-1}$ were 90 and 270 for rye, 140 and 420 for the legume–rye mixture, and 11 and 33 for mustard. December harvests were during Years 1 to 3, while other harvests were all 8 yr. Bars are means ± 95% confidence intervals. Within a harvest period, means topped with different letters are significantly different based on a Tukey–Kramer family-wise error rate of $p \leq 0.05$. Comparisons within a cover crop or between the legume–rye components and the monocultures can be made using the "rule of eye" method whereby intervals that overlap with a mean are not**

**Legend:** The thickness of the input and output arrows that cross the farm system boundary approximate the magnitude of the nitrogen (N) flux for fluxes > 10 kg ha$^{-1}$. Input values in light blue (i.e., all inputs other that cover crop seed and compost) were identical across all systems. The green arrows indicate N cycling through the soil between cover crops and vegetables and are 4 times thicker in the annually cover cropped systems to reflect more nitrogen cycling than occurred in Systems 1 and 2 that were only cover cropped every 4th winter. The inputs from cover crop seed and N fixation in Systems 1 and 2 are averaged across all 8 years even though cover crops were only grown every 4th winter. The purple arrows are the approximate N loss or storage below 30 cm. The box (without shading) in the bottom right for each system indicates the total N input ($N_{In}$) and exports in harvested vegetables ($N_{Out}$), and the difference (i.e., $N_{In}$ minus $N_{Out}$); and grey shaded box has the ratio of $N_{In}$ to $N_{Out}$ from total input (Tot.) and from fertilizers (Fert.).

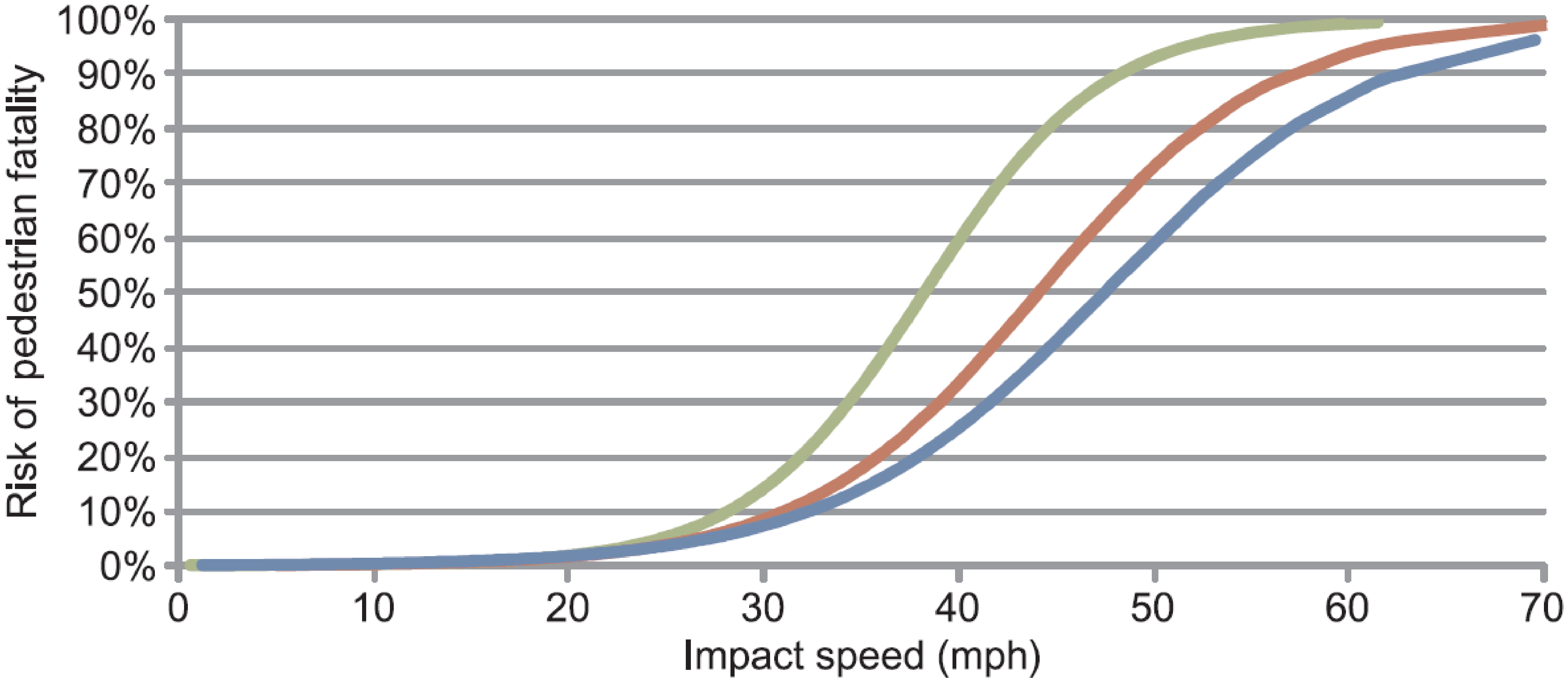
**Fig 11. Average annual nitrogen inputs, exports and storage or losses in** **years.** Values are in kg ha$^{-1}$ and were calculated from the compost additions, cover crop type and

**One measure of Soil Health**



Source: Brennan E.B., V. Acosta-Martinez. 2017. Cover cropping frequency is the main driver of soil microbial changes during six years of organic vegetable production. Soil Biology & Biochemistry 109:188-204.

# Speed Kills - The science is clear !



Source: https://nacto.org/docs/usdg/relationship_between_speed_risk_fatal_injury_pedestrians_and_car_occupants_richards.pdf

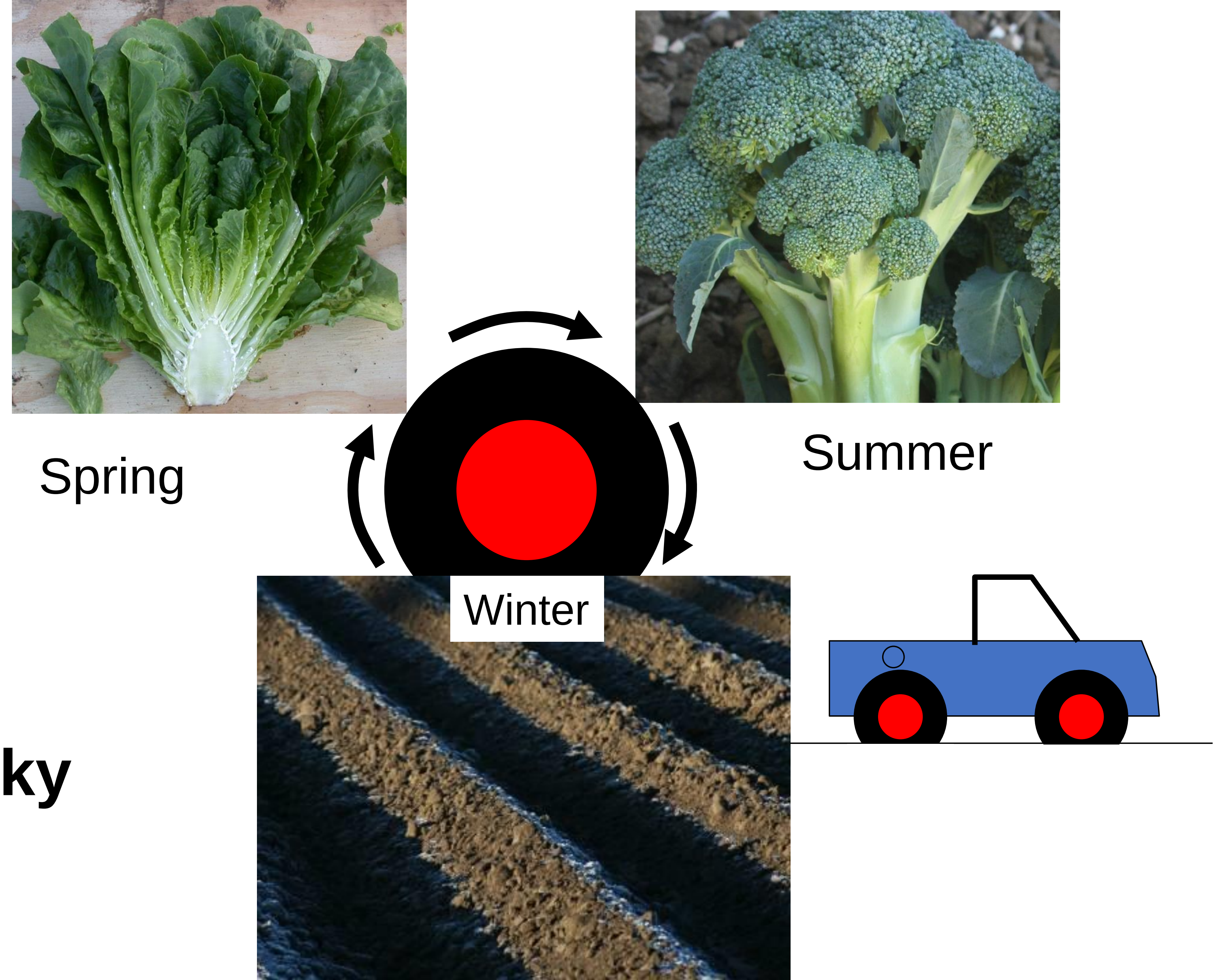
# But why do cars slow down?

# Think of Ag. Order 4.0 as a Speed Limit

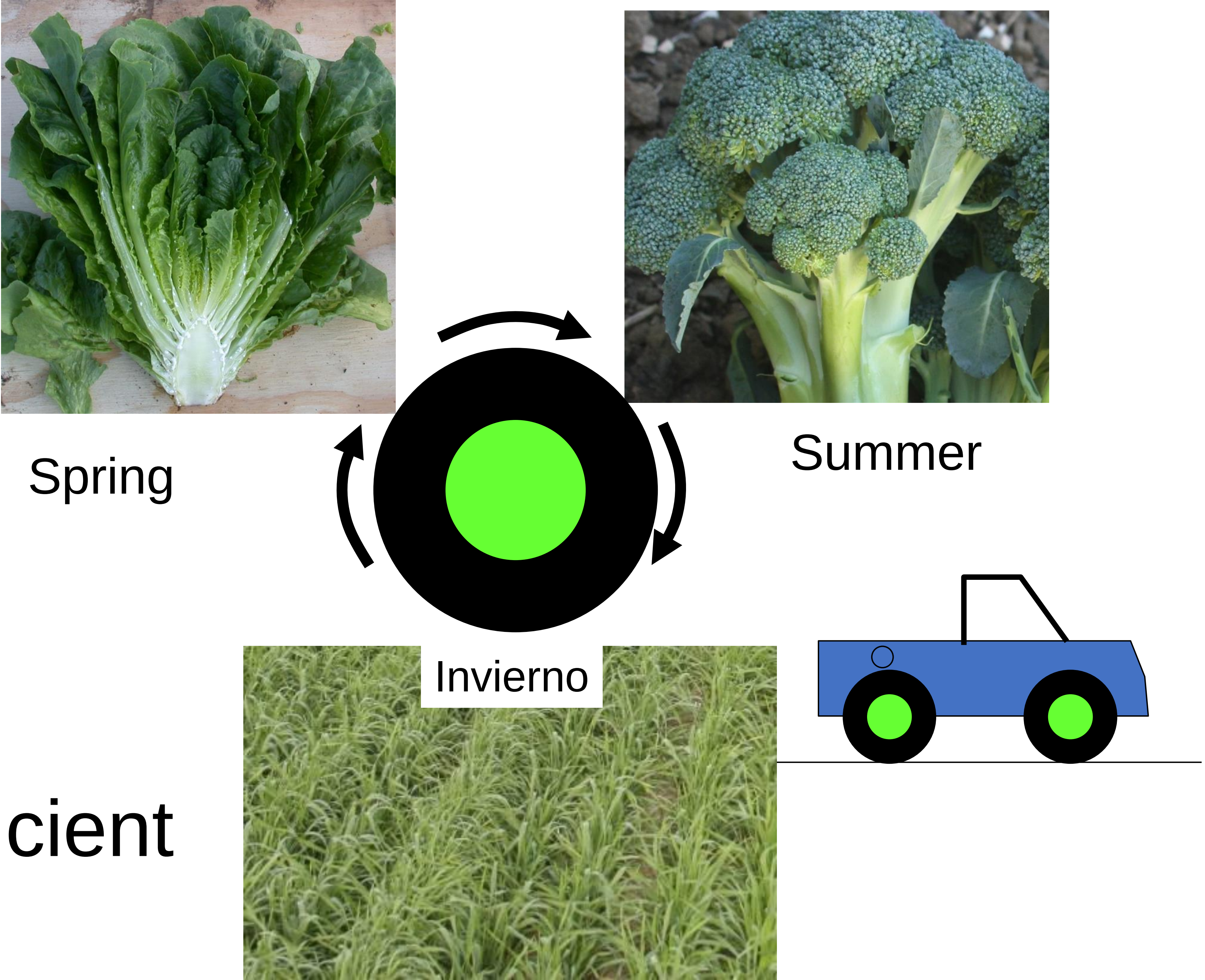
# Think of Ag. Order 4.0 as a Speed Limit

-Slow the loss of Nitrogen

-Increase it’s efficiency



**Leaky**



Spring

Summer

Invierno

Efficient

# Nonlegume cover crops reduce nitrate leaching

## The science is clear !

*In lettuce production . . .*

# Winter cover crops can decrease soil nitrate, leaching potential

Louise E. Jackson ❑ Lisa J. Wyland ❑ Jill A. Klein ❑ Richard F. Smith ❑ William E. Chaney
Steven T. Koike

***The large amounts of soil nitrate that can accumulate in annual row crop production during the winter fallow period can leach during winter storms and spring irrigation. In Monterey County, 48% of the wells in the upper unconfined aquifer exceed the public health drinking water standard of 10 ppm of nitrate-N. Nonleguminous cover crops, planted during the winter fallow and incorporated in early spring using reduced tillage equipment to maintain intact beds, have been found to reduce nitrate leaching without disrupting cropping schedules.***

The most efficient use of fertilizer and soil-derived nitrogen (N) occurs when availability coincides with plant demand. In cool-season vegetable production systems, most nitrate leaching occurs: (1) in the fallow period during winter rains when excess soil nitrate accumulates from residual fertilizer and from N mineralization and nitrification of crop residues and soil organic matter, and (2) during frequent irrigations in the final vegetable production growth stages.

Test results in the Salinas Valley show that high soil nitrate levels remain after vegetable harvest, and that concentrations often double during the winter fallow; net N mineralization reaches its annual maximum at this time. One objective in trying to reduce nitrate leaching therefore involves ways to recycle the excess residual soil N after the autumn harvest and to synchronize its release with uptake by the subsequent vegetable crop in early spring.

In other cropping systems, nonleguminous winter cover crops have been successfully employed to take up excess water and nitrate during the rainy fallow season, as well as to contribute to soil organic matter content after incorporation. A large volume of research has shown that increased organic matter leads to increased microbial activity in the soil, greater soil N turnover, greater aggregate stability, decreased soil crusting, increased water infiltration and ultimately enhanced fertility for the subsequent cash crop. With the development of techniques to grow and incorporate cover crops directly on semi-permanent beds, the constraints of time and expense typically involved in disking and reshaping beds will be eliminated.

In other studies, cover cropping has been shown to affect crop disease and insect pest management both positively and negatively. Cover crop cultivation may promote some soil fungal pathogens. Previous research has found that some cover crops can increase *Sclerotinia minor* inoculum which, combined with reduced tillage techniques, might threaten subsequent lettuce crops. Cover crop residue and reduced tillage practices can also increase some soil insect populations, although this can be beneficial in the case of natural predators. Cover crops and crop rotations have also been shown to suppress some soilborne diseases. For example, a study conducted in Salinas in 1986-88 found that corky root of lettuce can be partially suppressed by a winter cover crop of cereal rye.

## Field station trials

A preliminary trial, conducted on field station plots, evaluated several species for use as winter cover crops in rotation with annual row crops in the Salinas Valley. Desired characteristics included rapid growth and extensive root development in the upper soil profile during winter, to maximize nitrate and water uptake. In addition, it was assumed that the cover crop should be easy to incorporate on the beds, using minimum tillage techniques, and should not harbor diseases threatening to the subsequent cash crop.

**Methods.** A cover crop trial was established on field station research plots in Salinas, California, on November 15, 1989. Six species were planted in a randomized complete block design: oilseed radish (*Raphanus sativus* cv. Renova), white senf mustard (*Brassica hirta* cv. Martigena), white mustard (*Brassica alba*), phacelia (*Phacelia tanacetifolia* cv. Phaci), rye (*Secale cereale* cv. Merced) and annual ryegrass (*Lolium multiflorum*), along with a bare fallow plot in each block as a control. Soil samples to 60 cm

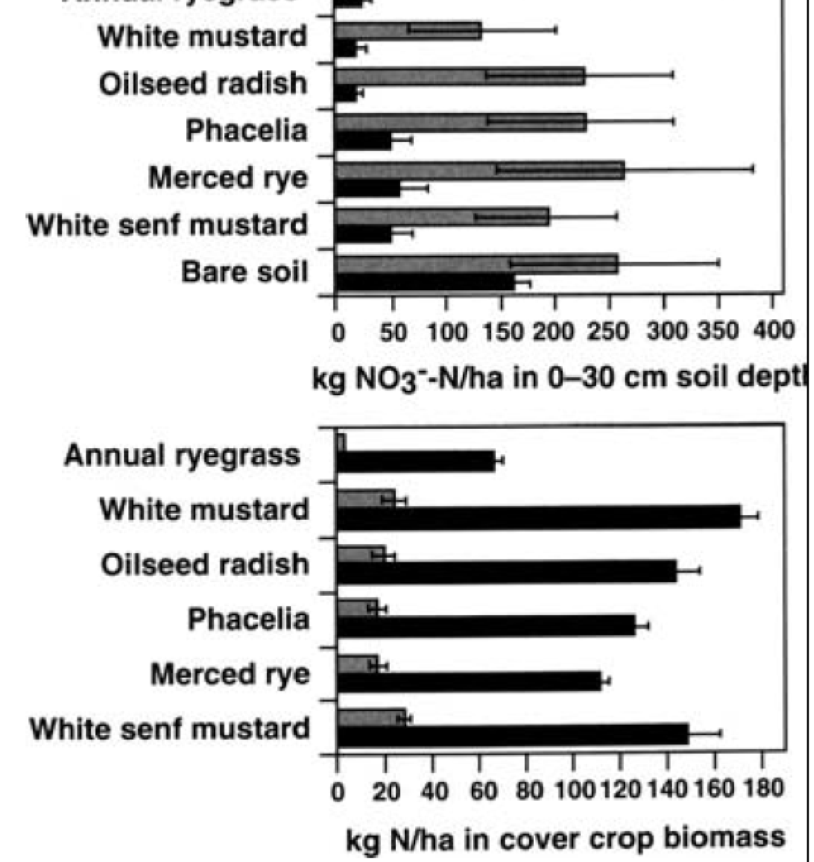
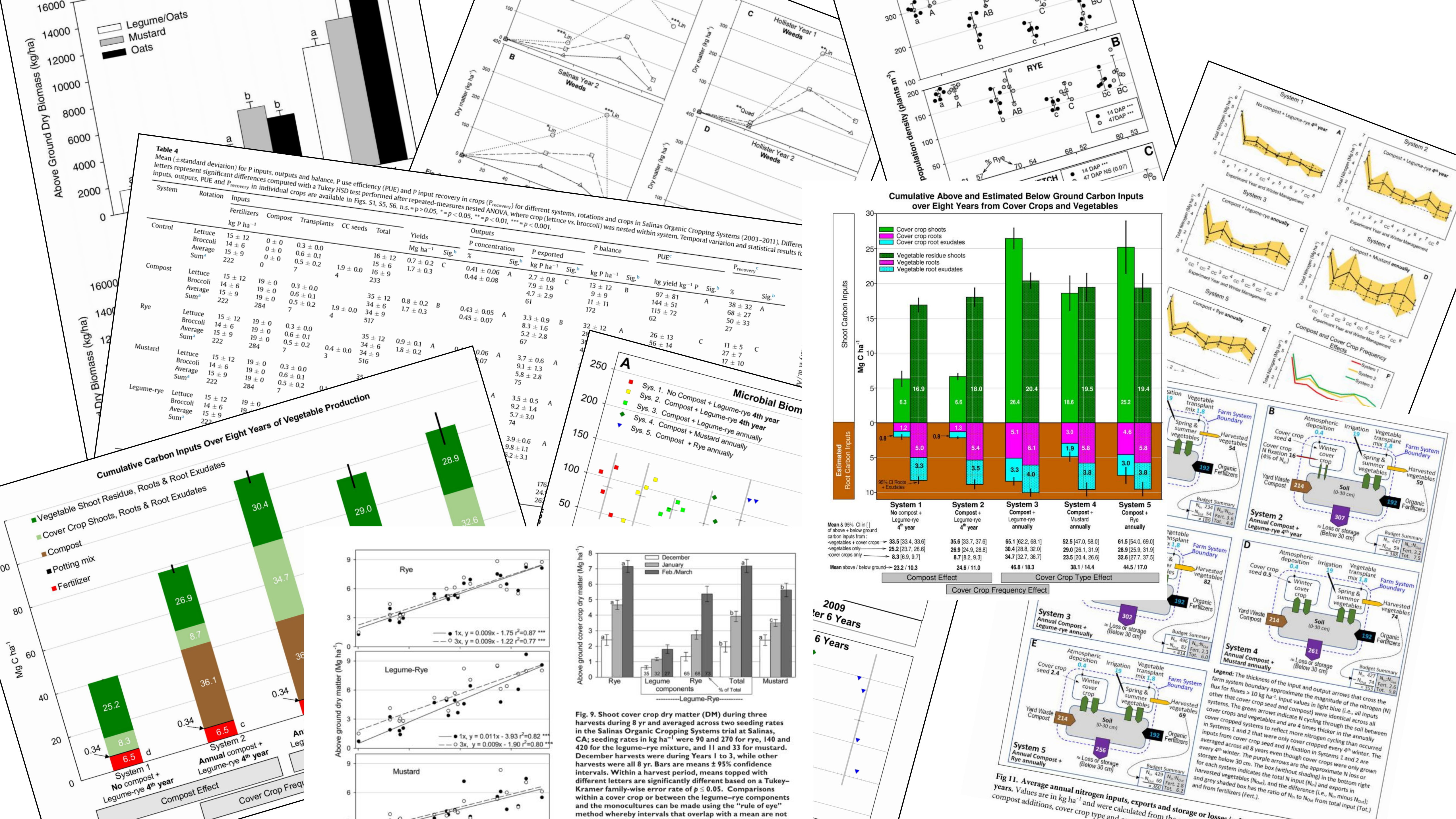


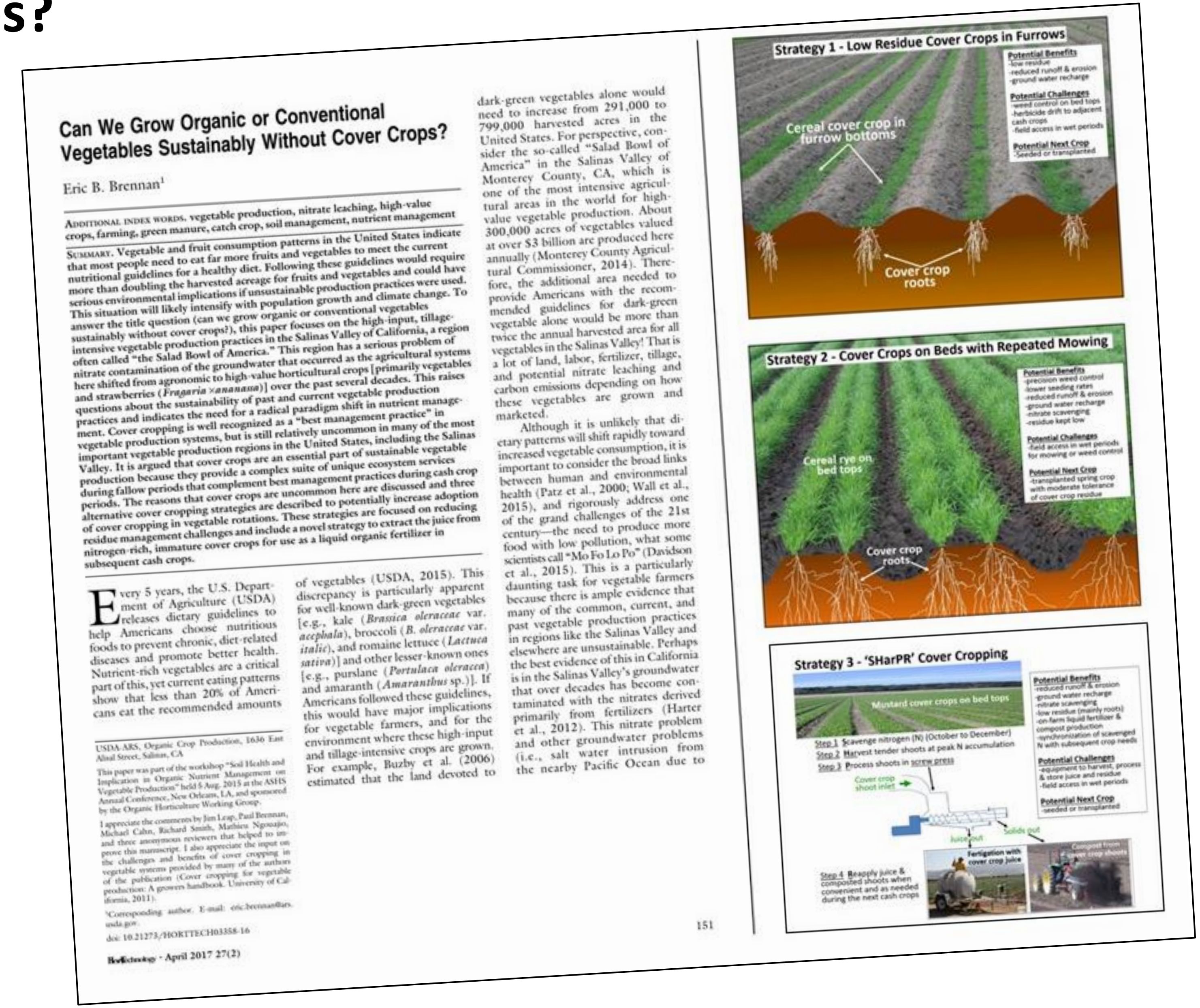
**Fig. 1 Mean nitrate content in the top 30 cm of soil, and N in the aboveground biomass of six cover crops compared to a bare soil control at mid-season in January (gray) and at incorporation in March (black), in an experimental trial in Salinas in 1990.**

Source: Jackson L.E., L.J. Wyland, J.A. Klein, R.F. Smith, W.E. Chaney, S. Koike. 1993. In lettuce production, winter cover crops can decrease soil nitrate, leaching potential. California Agriculture 47:12-15.


Above Ground Dry Biomass (kg/ha)
Legume/Oats
Mustard
Oats
Table 4
Mean (±standard deviation) for P inputs, outputs and balance, P use efficiency (PUE) and P input recovery in crops ($P_{recovery}$) for different systems, rotations and crops in Salinas Organic Cropping Systems (2003–2011).
Salinas Year 2 Weeds
Hollister Year 1 Weeds
Hollister Year 2 Weeds
RYE
Cumulative Above and Estimated Below Ground Carbon Inputs over Eight Years from Cover Crops and Vegetables
Cover crop shoots
Cover crop roots
Cover crop root exudates
Vegetable residue shoots
Vegetable roots
Vegetable root exudates
Shoot Carbon Inputs
Estimated Root Carbon Inputs
Mg C ha⁻¹
System 1
System 2
System 3
System 4
System 5
Compost Effect
Cover Crop Type Effect
Cover Crop Frequency Effect
Cumulative Carbon Inputs Over Eight Years of Vegetable Production
Vegetable Shoot Residue, Roots & Root Exudates
Cover Crop Shoots, Roots & Root Exudates
Compost
Potting mix
Fertilizer
Microbial Biom
Sys. 1. No Compost + Legume-rye 4th year
Sys. 2. Compost + Legume-rye 4th year
Sys. 3. Compost + Legume-rye annually
Sys. 4. Compost + Mustard annually
Sys. 5. Compost + Rye annually
Rye
Legume-Rye
Mustard
December
January
Feb./March
Above ground cover crop dry matter (Mg ha⁻¹)
Fig. 9. Shoot cover crop dry matter (DM) during three harvests during 8 yr and averaged across two seeding rates in the Salinas Organic Cropping Systems trial at Salinas, CA
Total Nitrogen (Mg ha⁻¹)
Farm System Boundary
Atmospheric deposition
Irrigation
Vegetable transplant mix
Harvested vegetables
Organic Fertilizers
Yard Waste Compost
Soil (0-30 cm)
Loss or storage (Below 30 cm)
Budget Summary
Fig 11. Average annual nitrogen inputs, exports and storage or losses

**What percentage of the land in the Central Coast of California is cover cropped during the winter?**

# Brennan E.B. 2017. Can we grow organic or conventional vegetables sustainably without cover crops?
# HortTechnology 27:151-161.



## Can We Grow Organic or Conventional Vegetables Sustainably Without Cover Crops?

Eric B. Brennan[1]

ADDITIONAL INDEX WORDS. vegetable production, nitrate leaching, high-value crops, farming, green manure, catch crop, soil management, nutrient management

SUMMARY. Vegetable and fruit consumption patterns in the United States indicate that most people need to eat far more fruits and vegetables to meet the current nutritional guidelines for a healthy diet. Following these guidelines would require more than doubling the harvested acreage for fruits and vegetables and could have serious environmental implications if unsustainable production practices were used. This situation will likely intensify with population growth and climate change. To answer the title question (can we grow organic or conventional vegetables sustainably without cover crops?), this paper focuses on the high-input, tillage-intensive vegetable production practices in the Salinas Valley of California, a region often called "the Salad Bowl of America." This region has a serious problem of nitrate contamination of the groundwater that occurred as the agricultural systems here shifted from agronomic to high-value horticultural crops [primarily vegetables and strawberries (*Fragaria ×ananassa*)] over the past several decades. This raises questions about the sustainability of past and current vegetable production practices and indicates the need for a radical paradigm shift in nutrient management. Cover cropping is well recognized as a "best management practice" in vegetable production systems, but is still relatively uncommon in many of the most important vegetable production regions in the United States, including the Salinas Valley. It is argued that cover crops are an essential part of sustainable vegetable production because they provide a complex suite of unique ecosystem services during fallow periods that complement best management practices during cash crop periods. The reasons that cover crops are uncommon here are discussed and three alternative cover cropping strategies are described to potentially increase adoption of cover cropping in vegetable rotations. These strategies are focused on reducing residue management challenges and include a novel strategy to extract the juice from nitrogen-rich, immature cover crops for use as a liquid organic fertilizer in subsequent cash crops.

Every 5 years, the U.S. Department of Agriculture (USDA) releases dietary guidelines to help Americans choose nutritious foods to prevent chronic, diet-related diseases and promote better health. Nutrient-rich vegetables are a critical part of this, yet current eating patterns show that less than 20% of Americans eat the recommended amounts of vegetables (USDA, 2015). This discrepancy is particularly apparent for well-known dark-green vegetables [e.g., kale (*Brassica oleraceae* var. *acephala*), broccoli (*B. oleraceae* var. *italic*), and romaine lettuce (*Lactuca sativa*)] and other lesser-known ones [e.g., purslane (*Portulaca oleracea*) and amaranth (*Amaranthus* sp.)]. If Americans followed these guidelines, this would have major implications for vegetable farmers, and for the environment where these high-input and tillage-intensive crops are grown. For example, Buzby et al. (2006) estimated that the land devoted to dark-green vegetables alone would need to increase from 291,000 to 799,000 harvested acres in the United States. For perspective, consider the so-called "Salad Bowl of America" in the Salinas Valley of Monterey County, CA, which is one of the most intensive agricultural areas in the world for high-value vegetable production. About 300,000 acres of vegetables valued at over $3 billion are produced here annually (Monterey County Agricultural Commissioner, 2014). Therefore, the additional area needed to provide Americans with the recommended guidelines for dark-green vegetable alone would be more than twice the annual harvested area for all vegetables in the Salinas Valley! That is a lot of land, labor, fertilizer, tillage, and potential nitrate leaching and carbon emissions depending on how these vegetables are grown and marketed.

Although it is unlikely that dietary patterns will shift rapidly toward increased vegetable consumption, it is important to consider the broad links between human and environmental health (Patz et al., 2000; Wall et al., 2015), and rigorously address one of the grand challenges of the 21st century—the need to produce more food with low pollution, what some scientists call "Mo Fo Lo Po" (Davidson et al., 2015). This is a particularly daunting task for vegetable farmers because there is ample evidence that many of the common, current, and past vegetable production practices in regions like the Salinas Valley and elsewhere are unsustainable. Perhaps the best evidence of this in California is in the Salinas Valley's groundwater that over decades has become contaminated with the nitrates derived primarily from fertilizers (Harter et al., 2012). This nitrate problem and other groundwater problems (i.e., salt water intrusion from the nearby Pacific Ocean due to

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This paper was part of the workshop "Soil Health and Implication in Organic Nutrient Management on Vegetable Production" held 5 Aug. 2015 at the ASHS Annual Conference, New Orleans, LA, and sponsored by the Organic Horticulture Working Group.

I appreciate the comments by Jim Leap, Paul Brennan, Michael Cahn, Richard Smith, Mathieu Ngouajio, and three anonymous reviewers that helped to improve this manuscript. I also appreciate the input on the challenges and benefits of cover cropping in vegetable systems provided by many of the authors of the publication (Cover cropping for vegetable production: A growers handbook. University of California, 2011).

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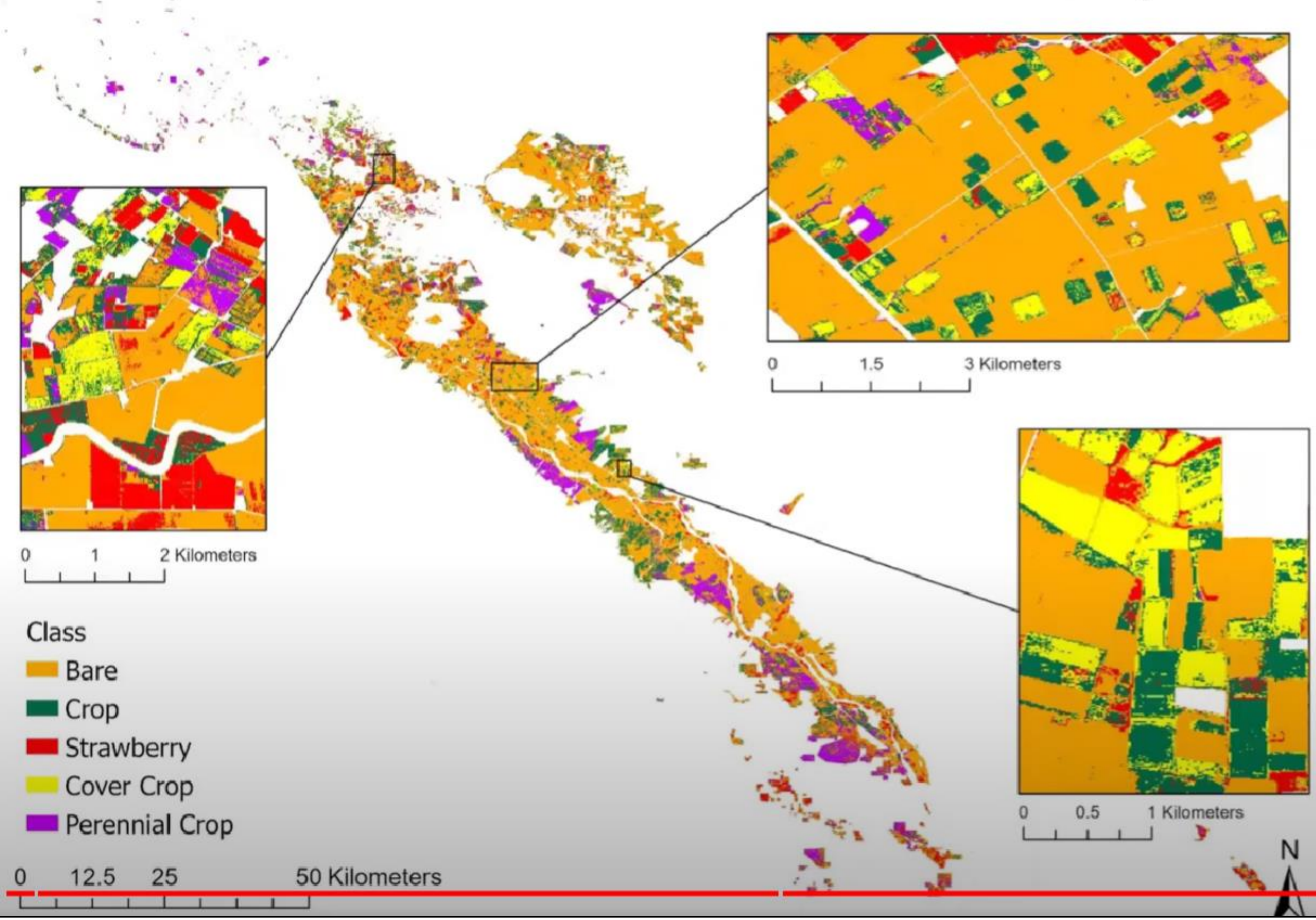
Remote Sensing of Winter Cover Crops in the Central Coast Region of California

Jennifer Symonds

4/17/21

**Remote sensing of winter cover crops in the central coast region of California**
https://www.youtube.com/watch?v=qZ_GE9LPbfA
By Jennifer Symonds. Senior undergraduate honors research (Dr. Tim Bowles, UC Berkeley Agroecology Lab)

# Central Coast Crop Cover



## Accuracy

**RF: 86.7%**

CART: 74.7%

## Classes

Bare: **58.1%**
(881.8 sq km)

Crop: **15.0%**
(228.0 sq km)

Perennial Crop: **11.4%**
(172.6 sq km)

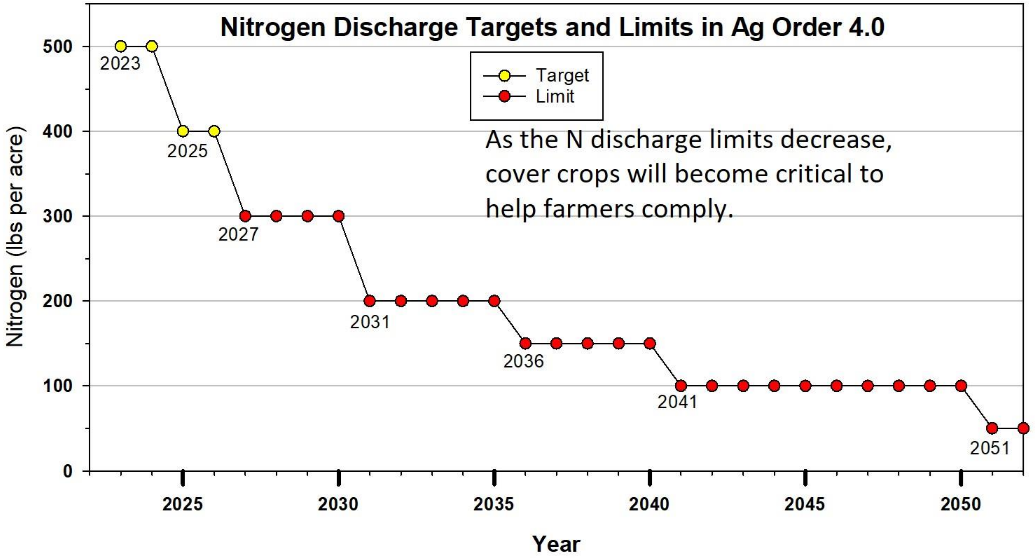
Strawberry: **10.7%**
(162.7 sq km)

Cover Crop: **4.8%**
(72.6 sq km)

# Ag. Order 4.0
# will increase cover cropping !

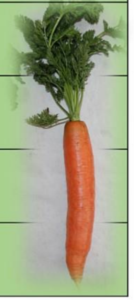
# **Ag. Order 4.0** Regulation, & **Cover Crop Nitrogen Scavenging Credits**

A ‘game-changing’ regulation to protect & improve surface & ground water quality by limiting nitrogen (N) discharge. It affects 540,000 acres of irrigated land in the Central Coast of California & incentivizes cover cropping & more efficient use of N inputs.



As the N discharge limits decrease, cover crops will become critical to help farmers comply.

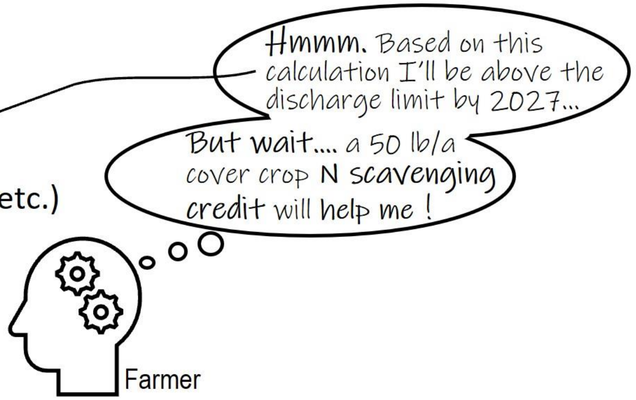
### Two Types of Cover Crop Nitrogen Scavenging Credits (i.e., ‘$R_{scavenge}$’)

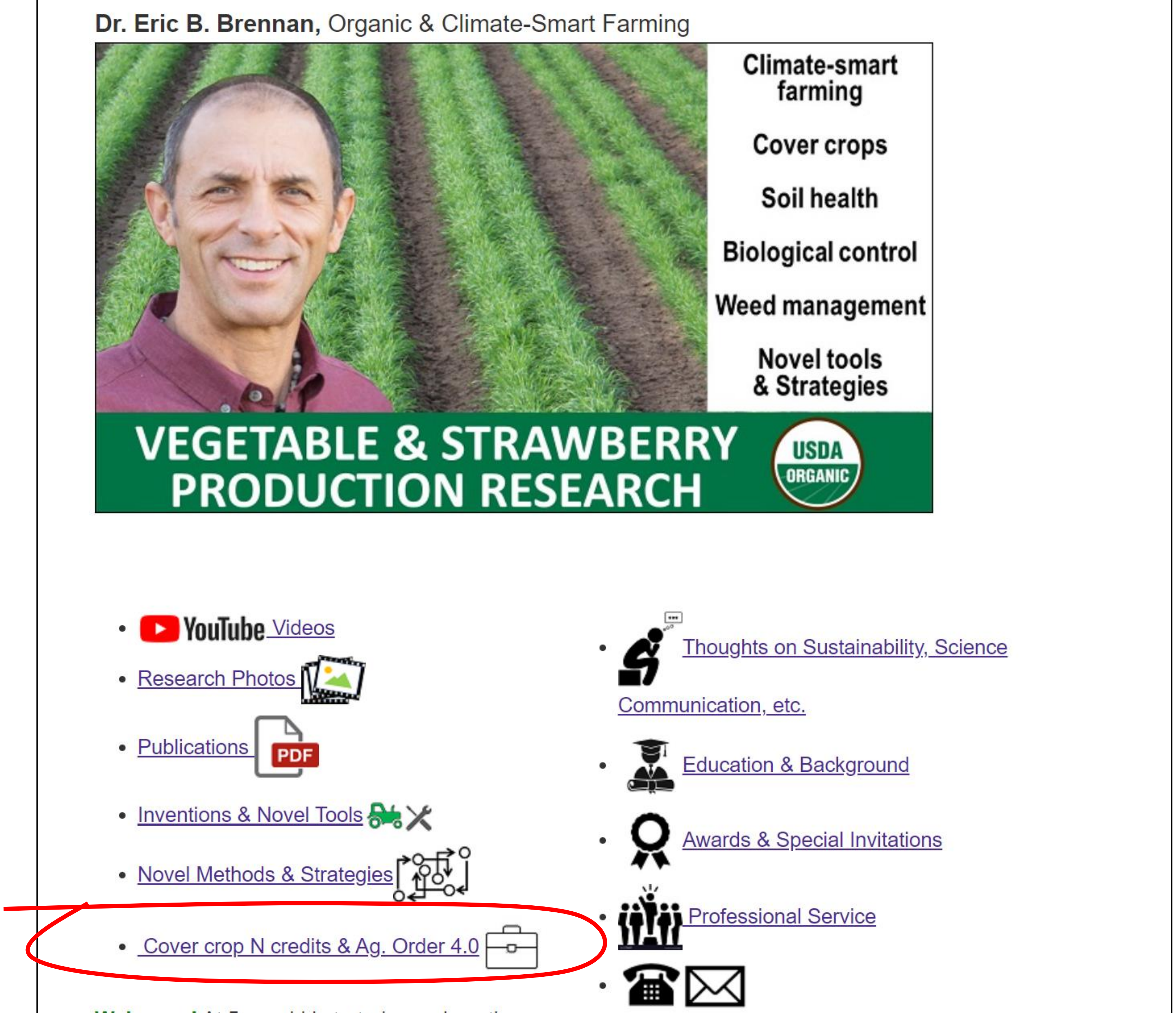
| **Requirements** | Option 1. **Standard Credit** (30 lb N/acre) | Option 2. **Calculated Credit** (97% of Shoot N uptake) |
|---|---|---|
| Non-legume cover crop | ✓  | ✓  |
| Grows for 90 days (October to April) | ✓ | ✓ |
| Oven-dry* Shoot Biomass (4500 lb/acre) | ✓ | ✓ |
| Carbon : Nitrogen ratio (≥20:1) | | ✓ |

*Oven-dried at 149-150°F (98% dry matter)

<u>Example of N Discharge calculation</u>

450 lbs N /acre (**Applied** as fertilizer, irrigation etc.)
-100 lbs N /acre (**Removed** in harvest)
=350 lbs N /acre **Nitrogen Discharge**)





**Dr. Eric B. Brennan,** Organic & Climate-Smart Farming

Climate-smart farming

Cover crops

Soil health

Biological control

Weed management

Novel tools & Strategies

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- Thoughts on Sustainability, Science Communication, etc.
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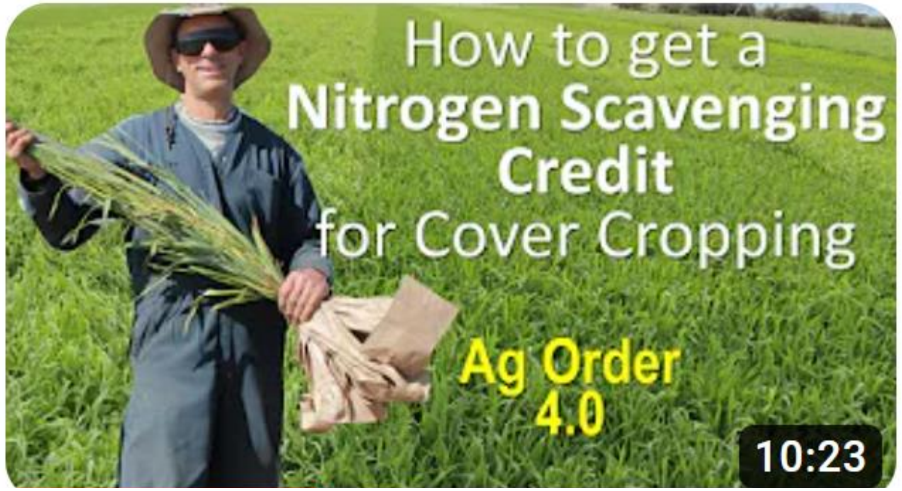
A Simple Method to Help Farmers Estimate Cereal Cover Crop Shoot Biomass.

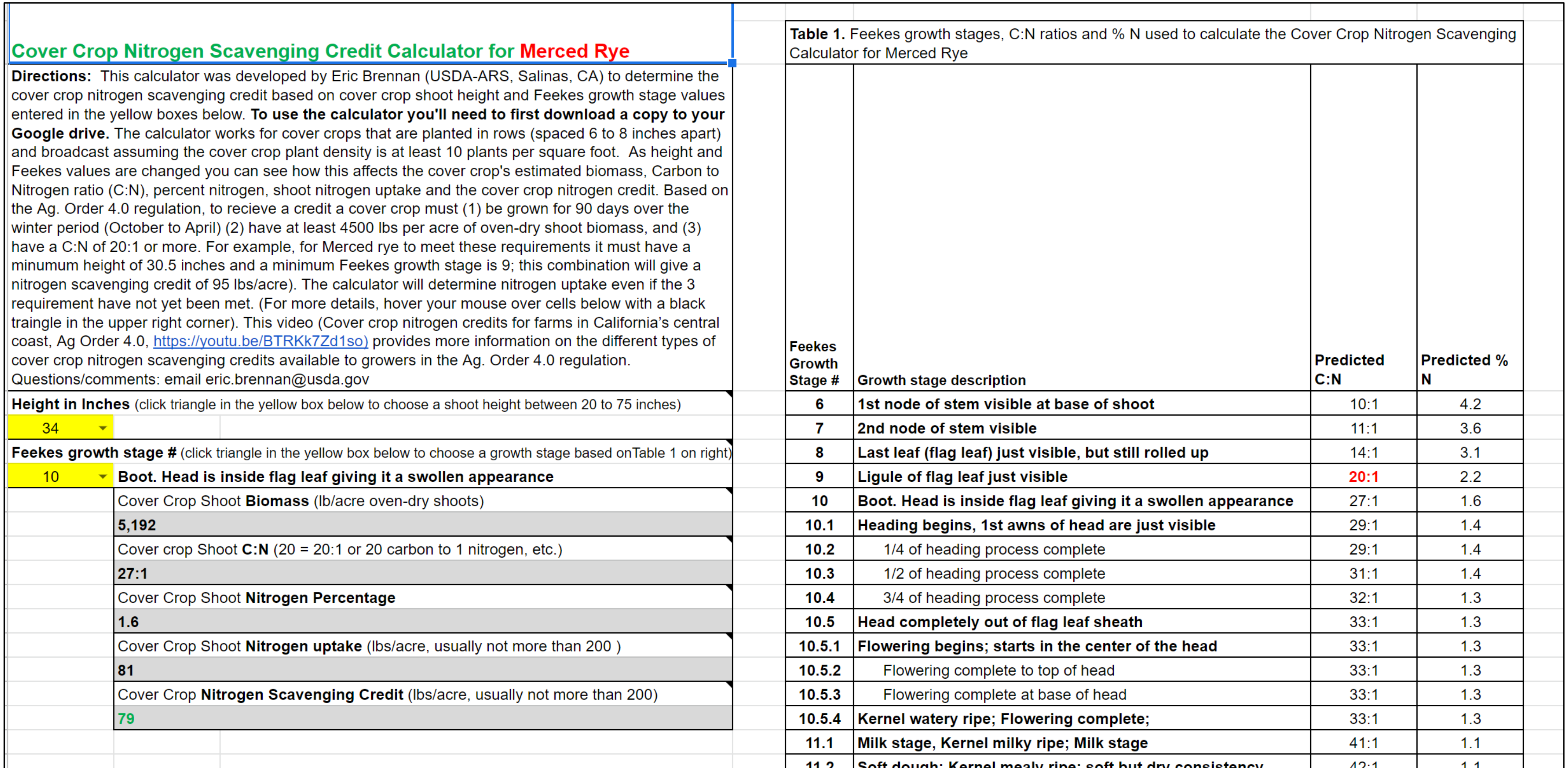


Cover crop nitrogen credits for farms in California's central coast, Ag Order 4.0.

Historical Win for Farmers, Cover Crops & Ground Water Protection in California's Central Coast.

Advocating for Cover Crop Nitrogen Credits -Ag Order 4.0 Adoption hearing, Central Coast Water Board.

# Google Sheet calculators



## Cover Crop Nitrogen Scavenging Credit Calculator for Merced Rye

**Directions:** This calculator was developed by Eric Brennan (USDA-ARS, Salinas, CA) to determine the cover crop nitrogen scavenging credit based on cover crop shoot height and Feekes growth stage values entered in the yellow boxes below. **To use the calculator you'll need to first download a copy to your Google drive.** The calculator works for cover crops that are planted in rows (spaced 6 to 8 inches apart) and broadcast assuming the cover crop plant density is at least 10 plants per square foot. As height and Feekes values are changed you can see how this affects the cover crop's estimated biomass, Carbon to Nitrogen ratio (C:N), percent nitrogen, shoot nitrogen uptake and the cover crop nitrogen credit. Based on the Ag. Order 4.0 regulation, to recieve a credit a cover crop must (1) be grown for 90 days over the winter period (October to April) (2) have at least 4500 lbs per acre of oven-dry shoot biomass, and (3) have a C:N of 20:1 or more. For example, for Merced rye to meet these requirements it must have a minumum height of 30.5 inches and a minimum Feekes growth stage is 9; this combination will give a nitrogen scavenging credit of 95 lbs/acre). The calculator will determine nitrogen uptake even if the 3 requirement have not yet been met. (For more details, hover your mouse over cells below with a black traingle in the upper right corner). This video (Cover crop nitrogen credits for farms in California's central coast, Ag Order 4.0, https://youtu.be/BTRKk7Zd1so) provides more information on the different types of cover crop nitrogen scavenging credits available to growers in the Ag. Order 4.0 regulation. Questions/comments: email eric.brennan@usda.gov

**Height in Inches** (click triangle in the yellow box below to choose a shoot height between 20 to 75 inches)

34 ▾

**Feekes growth stage #** (click triangle in the yellow box below to choose a growth stage based onTable 1 on right)

10 ▾ **Boot. Head is inside flag leaf giving it a swollen appearance**

Cover Crop Shoot **Biomass** (lb/acre oven-dry shoots)

**5,192**

Cover crop Shoot **C:N** (20 = 20:1 or 20 carbon to 1 nitrogen, etc.)

**27:1**

Cover Crop Shoot **Nitrogen Percentage**

**1.6**

Cover Crop Shoot **Nitrogen uptake** (lbs/acre, usually not more than 200 )

**81**

Cover Crop **Nitrogen Scavenging Credit** (lbs/acre, usually not more than 200)

**79**

**Table 1.** Feekes growth stages, C:N ratios and % N used to calculate the Cover Crop Nitrogen Scavenging Calculator for Merced Rye

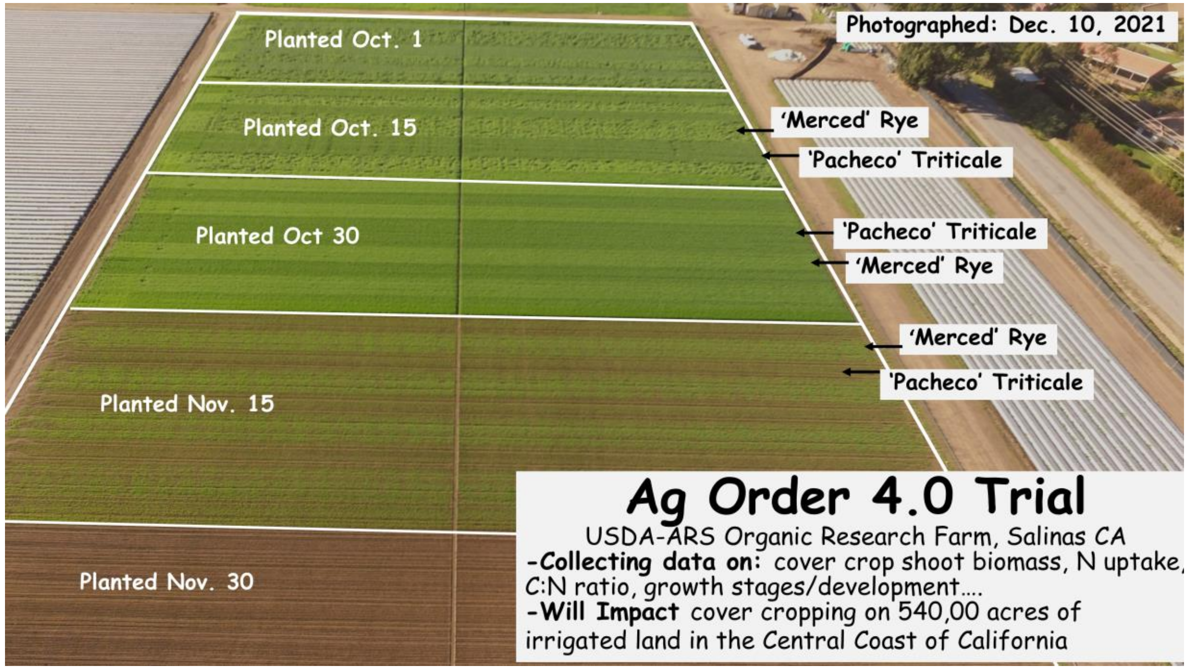
| Feekes Growth Stage # | Growth stage description | Predicted C:N | Predicted % N |
|---|---|---|---|
| 6 | **1st node of stem visible at base of shoot** | 10:1 | 4.2 |
| 7 | **2nd node of stem visible** | 11:1 | 3.6 |
| 8 | **Last leaf (flag leaf) just visible, but still rolled up** | 14:1 | 3.1 |
| 9 | **Ligule of flag leaf just visible** | 20:1 | 2.2 |
| 10 | **Boot. Head is inside flag leaf giving it a swollen appearance** | 27:1 | 1.6 |
| 10.1 | **Heading begins, 1st awns of head are just visible** | 29:1 | 1.4 |
| 10.2 | 1/4 of heading process complete | 29:1 | 1.4 |
| 10.3 | 1/2 of heading process complete | 31:1 | 1.4 |
| 10.4 | 3/4 of heading process complete | 32:1 | 1.3 |
| 10.5 | **Head completely out of flag leaf sheath** | 33:1 | 1.3 |
| 10.5.1 | **Flowering begins; starts in the center of the head** | 33:1 | 1.3 |
| 10.5.2 | Flowering complete to top of head | 33:1 | 1.3 |
| 10.5.3 | Flowering complete at base of head | 33:1 | 1.3 |
| 10.5.4 | **Kernel watery ripe; Flowering complete;** | 33:1 | 1.3 |
| 11.1 | **Milk stage, Kernel milky ripe; Milk stage** | 41:1 | 1.1 |
| 11.2 | **Soft dough; Kernel mealy ripe; soft but dry consistency** | 42:1 | 1.1 |

# On-going Cover Crop Research at USDA-ARS to help growers get N scavenging Credits

2021-22 Planting date trials (Richard Smith, UCCE and helpers for RCD)

-2022-23 Seeding rate trials with Merced rye and Pacheco triticale to save seed and suppress weeds. Cereal mixes

-N mineralization studies with diff C:N ratios (Collaboration with Daniel Geiseller, Richard Smith, Anna Gomes)



**Ag Order 4.0 Trial**

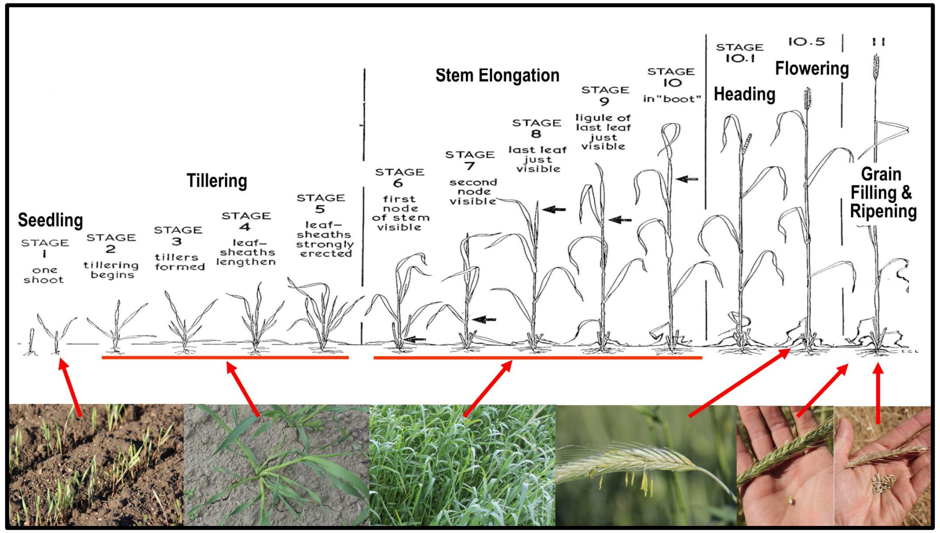
USDA-ARS Organic Research Farm, Salinas CA

-**Collecting data on:** cover crop shoot biomass, N uptake, C:N ratio, growth stages/development....

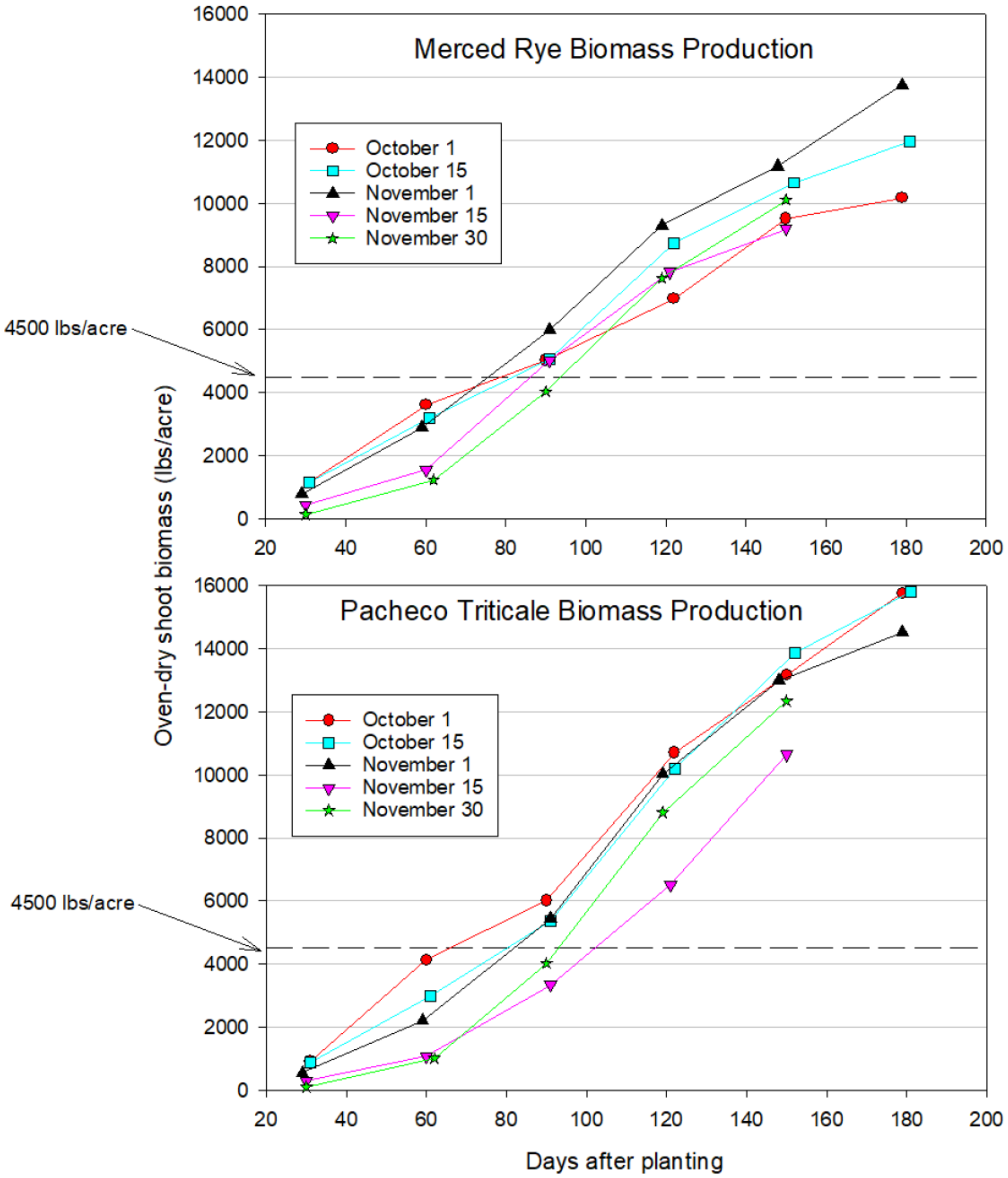
-**Will Impact** cover cropping on 540,00 acres of irrigated land in the Central Coast of California

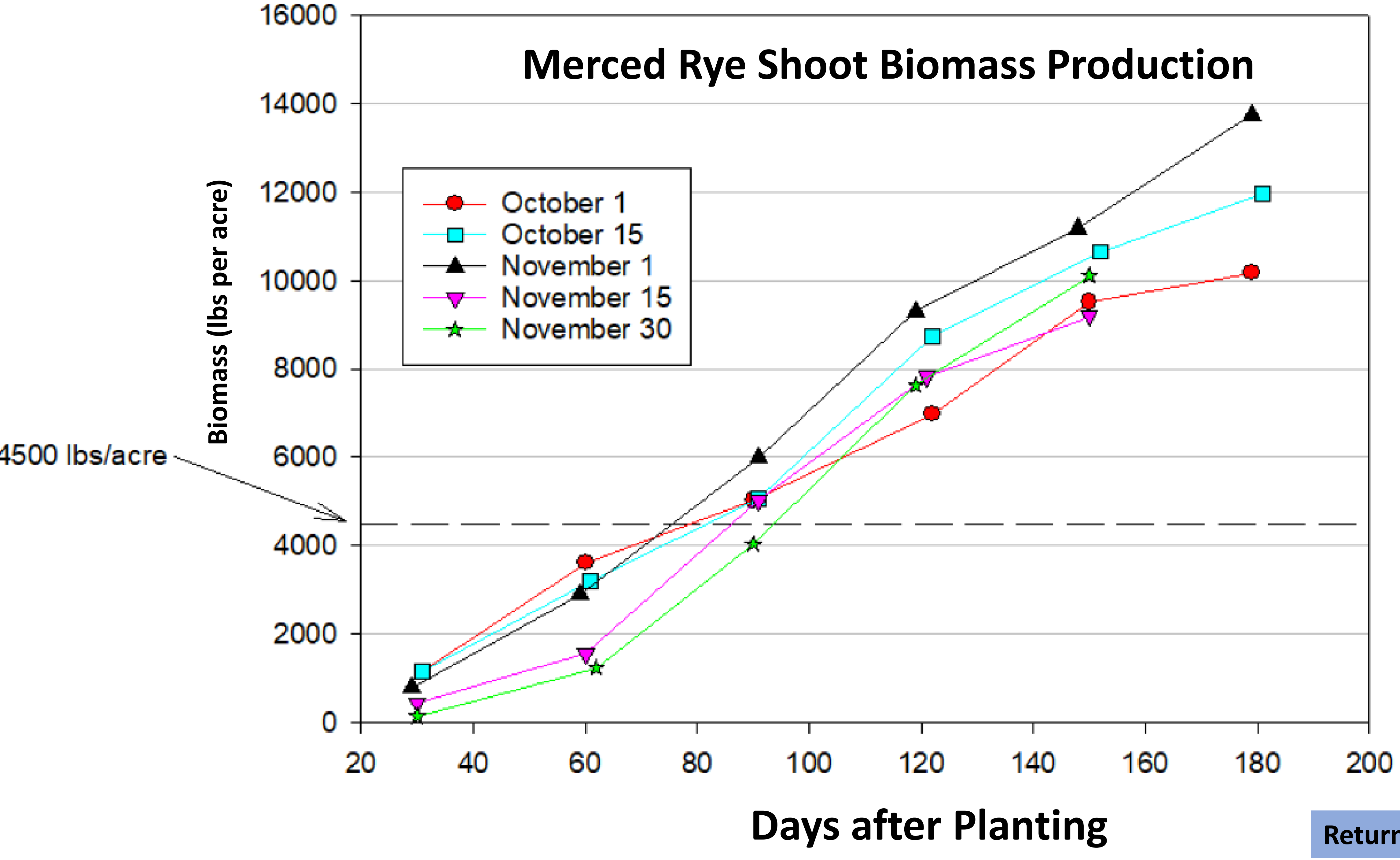
Stay Tuned !

# 4 Tips for growers to maximize cover crop benefits in Ag. Order 4.0 and beyond.



# **TIP 1.** Get your seed early, plant early.


Merced Rye Biomass Production
October 1
October 15
November 1
November 15
November 30
4500 lbs/acre
0
2000
4000
6000
8000
10000
12000
14000
16000
20
40
60
80
100
120
140
160
180
200
Pacheco Triticale Biomass Production
October 1
October 15
November 1
November 15
November 30
4500 lbs/acre
Oven-dry shoot biomass (lbs/acre)
Days after planting



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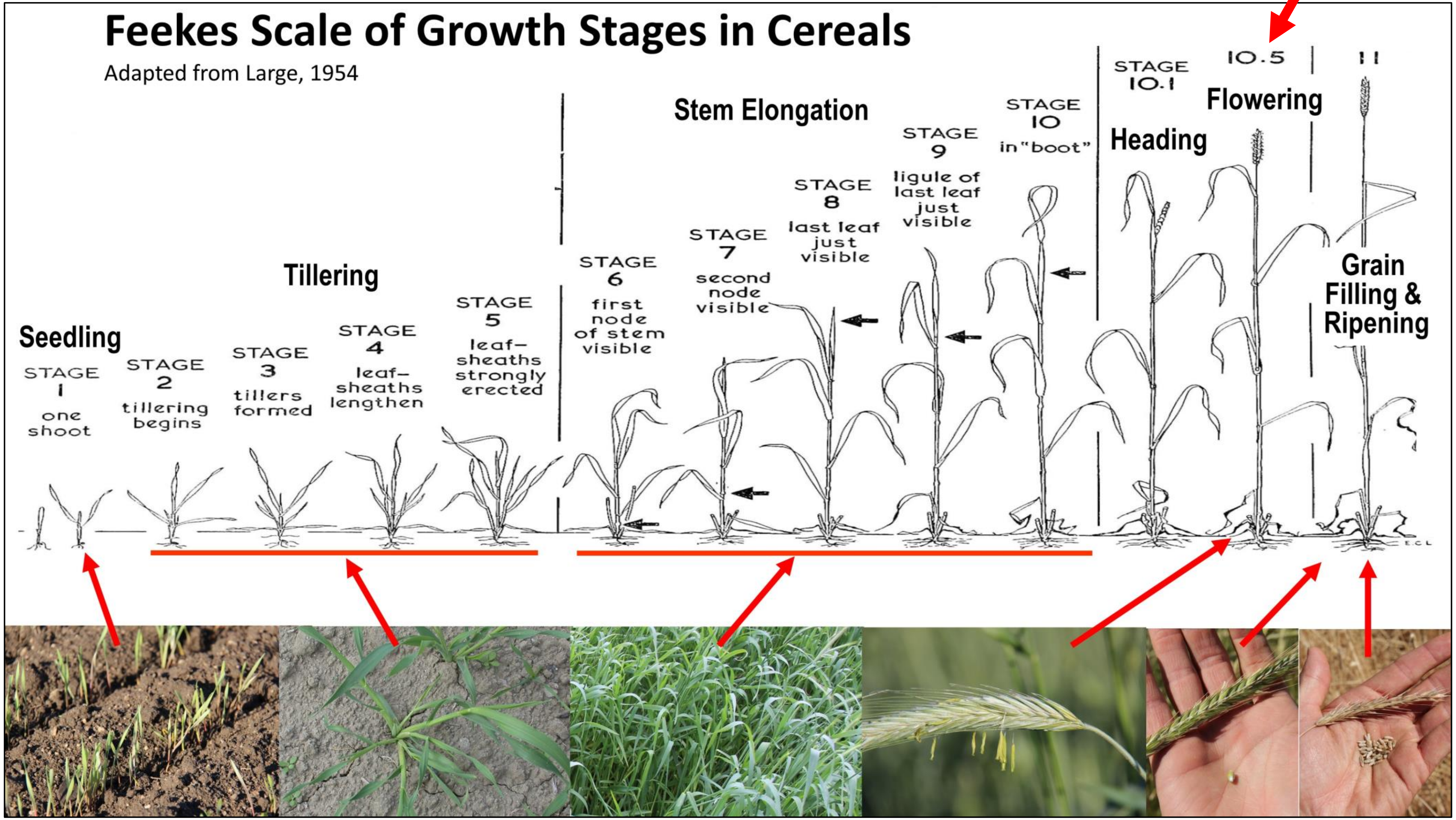
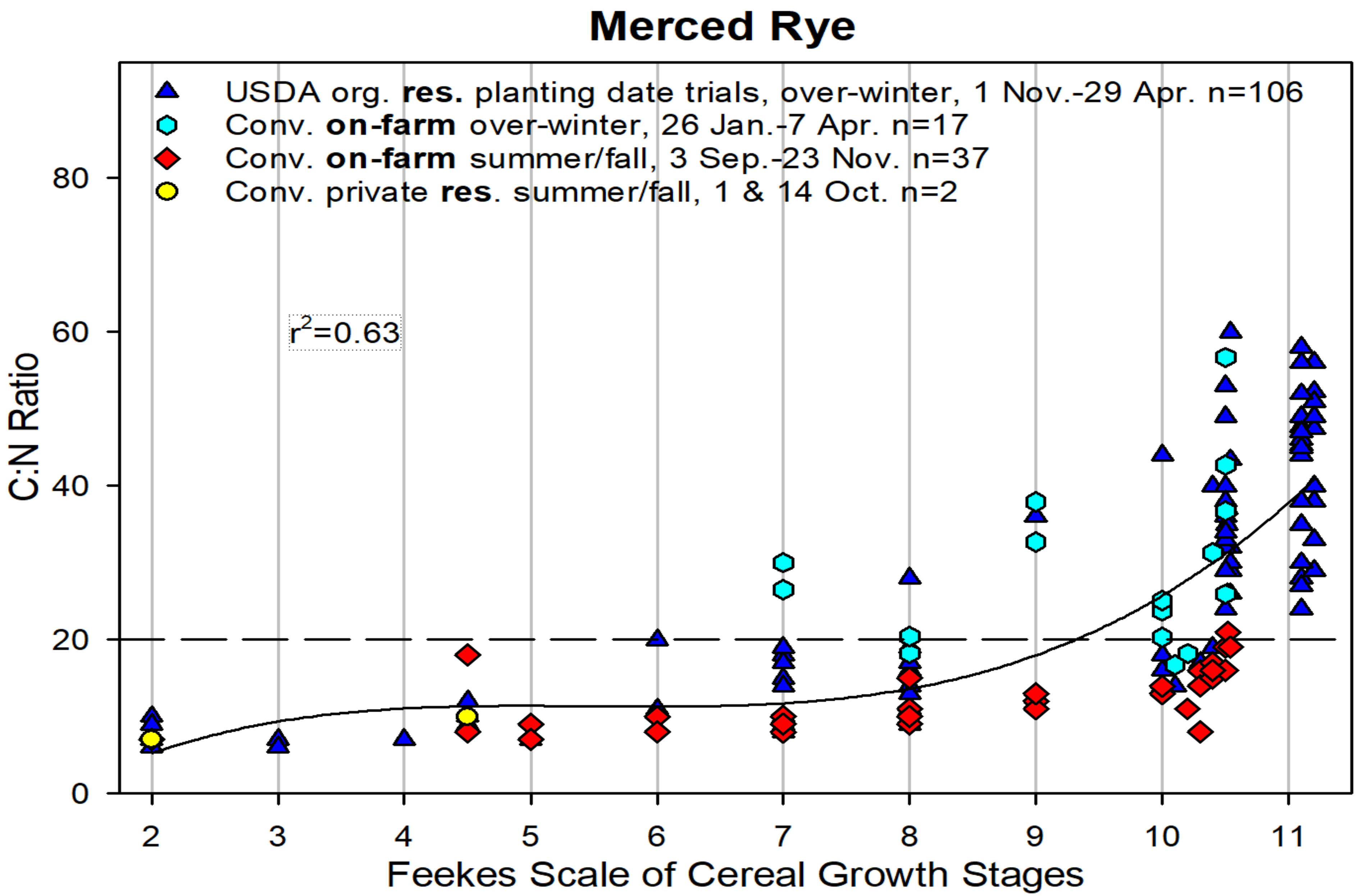
# **TIP 2.** Learn Feekes (Know Feekes, No Freaking out !)



Feekes Scale of Growth Stages in Cereals

Adapted from Large, 1954

# We can estimate C:N ratio of Rye from the Feekes Scale ☺



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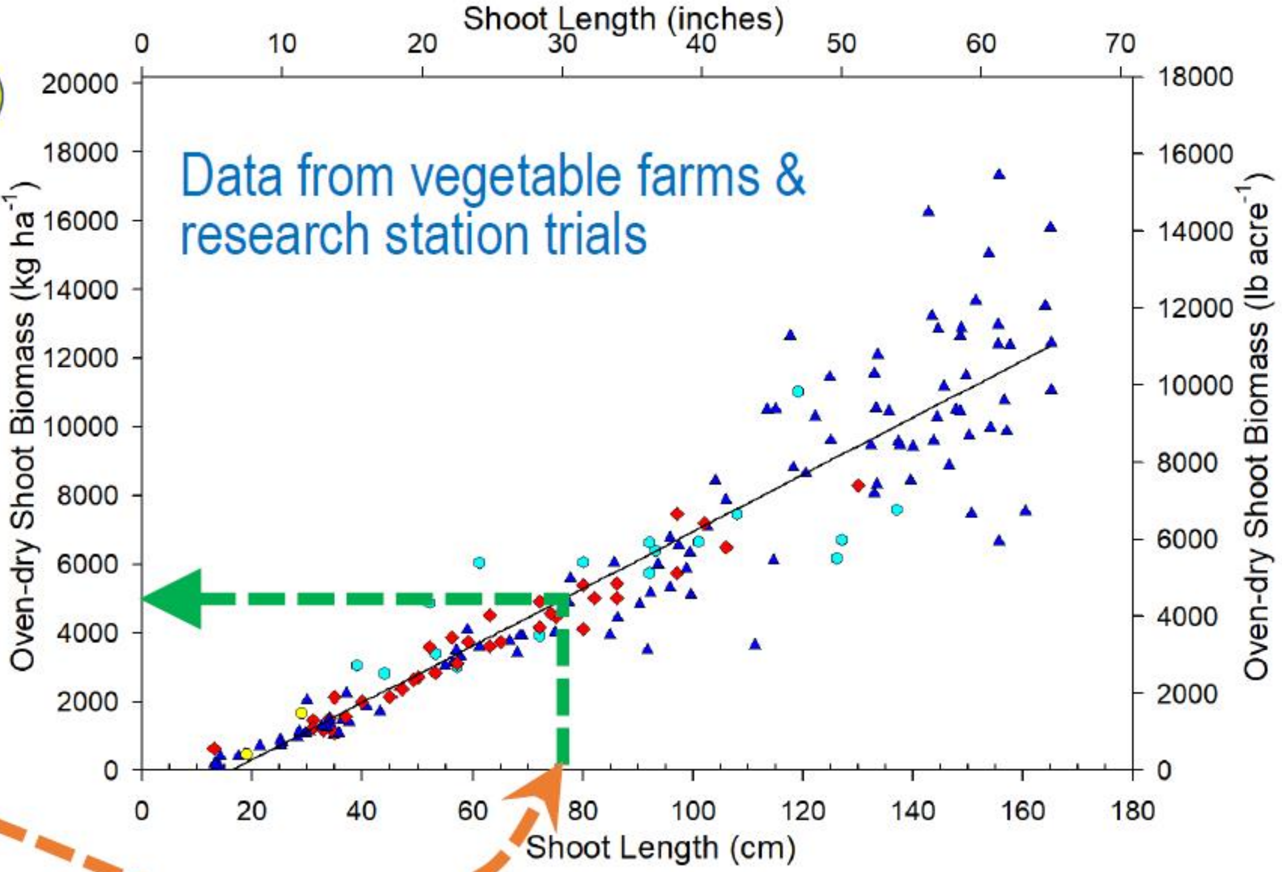
# **TIP 3.** Learn to estimate shoot biomass

I can **estimate cover crop biomass from** the **shoot length** of just **10 plants !!!**

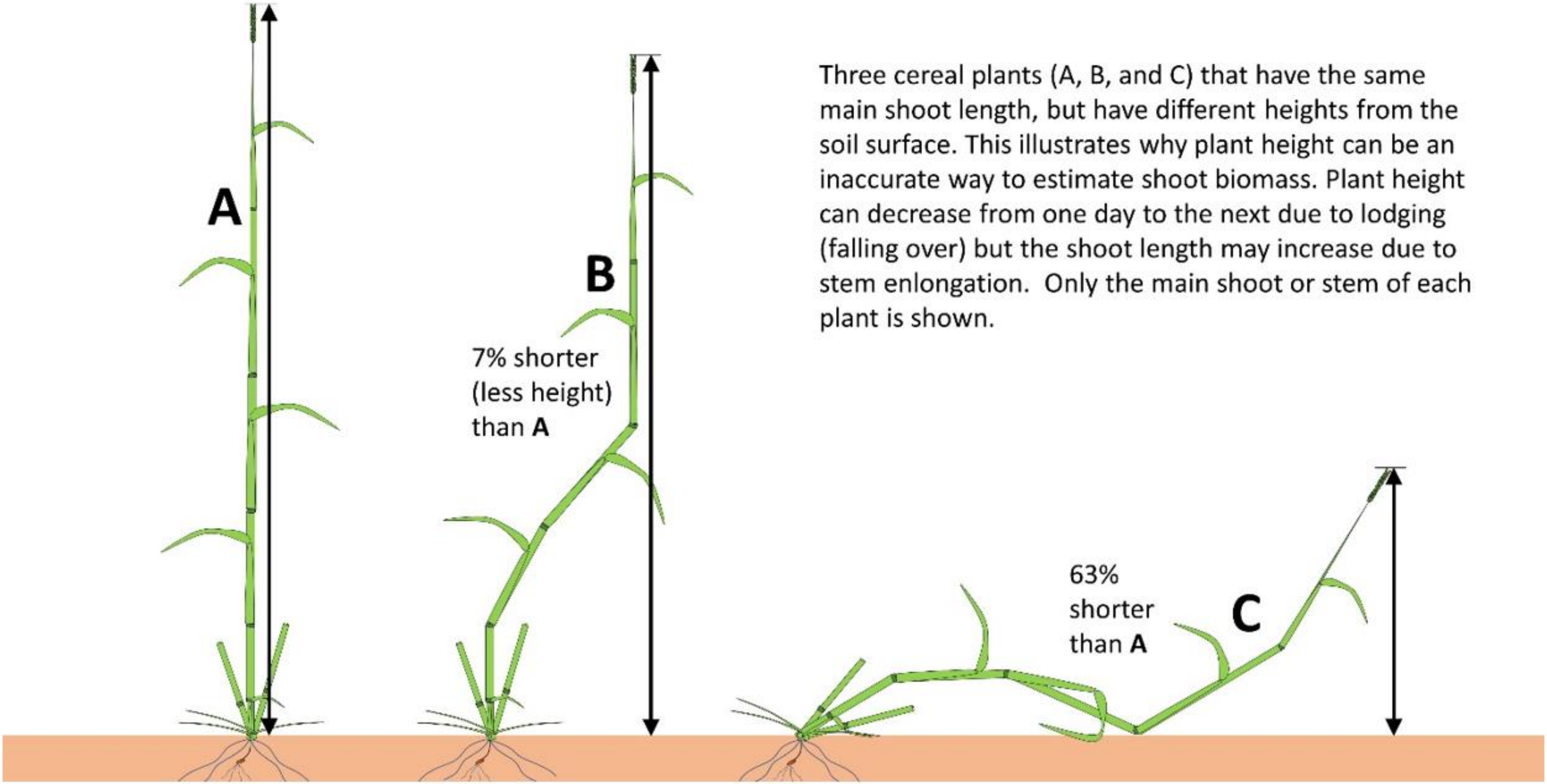


Data from vegetable farms & research station trials

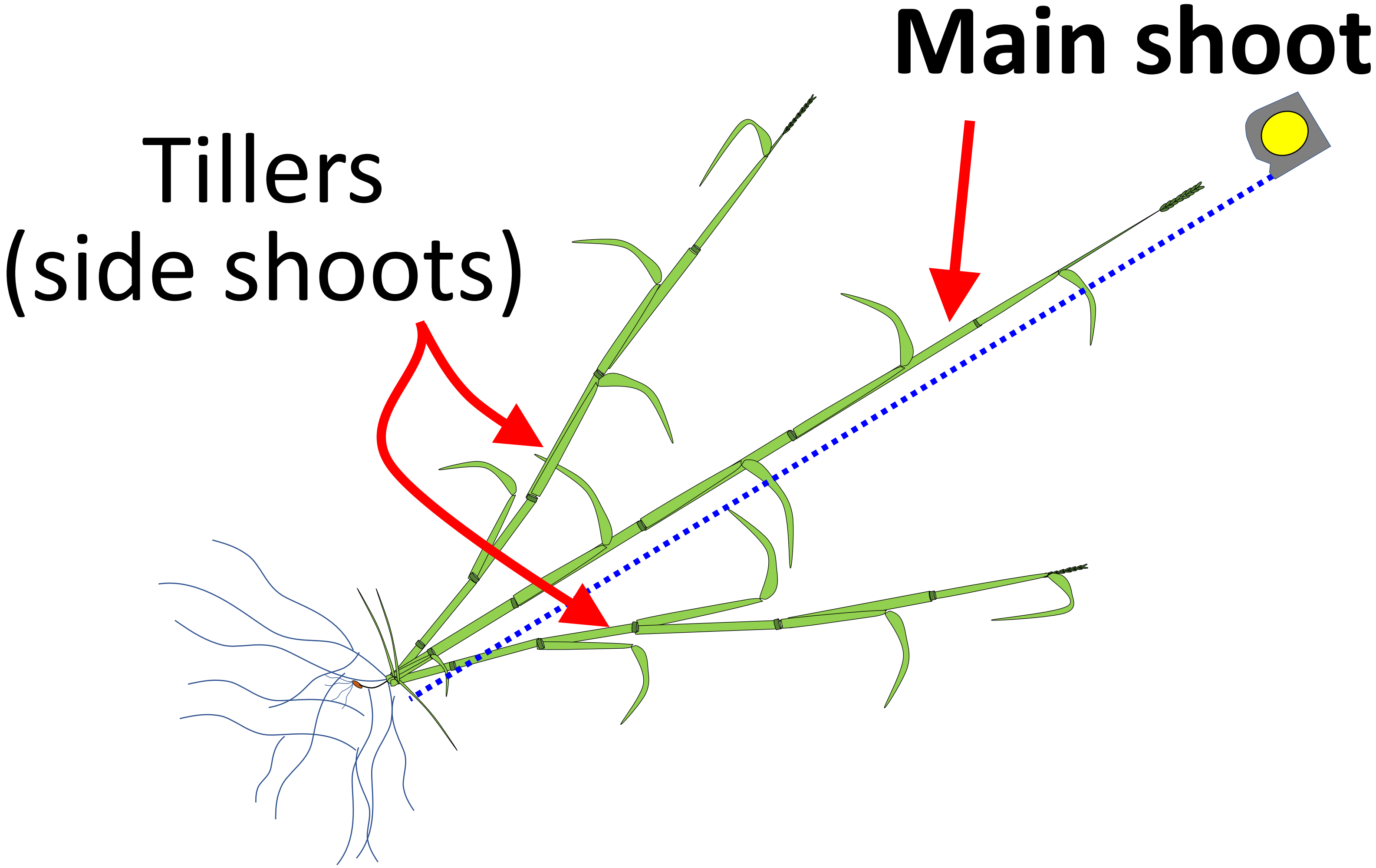
- **A Farmer-friendly**, field-based method to improve improve **nitrogen management** & **cover crop adoption**.
- This affects more the **200,000 hectares** of irrigated land on the central coast of California.
- **Rye** ($r^2$=0.87) & **Triticale** ($r^2$=0.88).

A Simple Method to Help Farmers Estimate Cereal Cover Crop Shoot Biomass.

# Same Shoot Length **but** Different Heights



Three cereal plants (A, B, and C) that have the same main shoot length, but have different heights from the soil surface. This illustrates why plant height can be an inaccurate way to estimate shoot biomass. Plant height can decrease from one day to the next due to lodging (falling over) but the shoot length may increase due to stem enlongation.  Only the main shoot or stem of each plant is shown.



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# **TIP 4.** Calibrate your drill

Save seed

Suppress weeds

# Calibrate your drill to **Save seed**

# Calibrate your drill to **Suppress weeds**

## 37 Days after planting

55 Days after planting

High seeding rate

Low seeding rate

# Calibrate your drill to **Suppress weeds**

High cover crop seeding rate

Low cover crop seeding rate

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