THE SHORT BALD AGRONOMIST

LIVE THE GOLDEN & SILVER RULE

SOYBEAN NODULATION & NITROGEN FIXATION

Part 1: INTRODUCTION

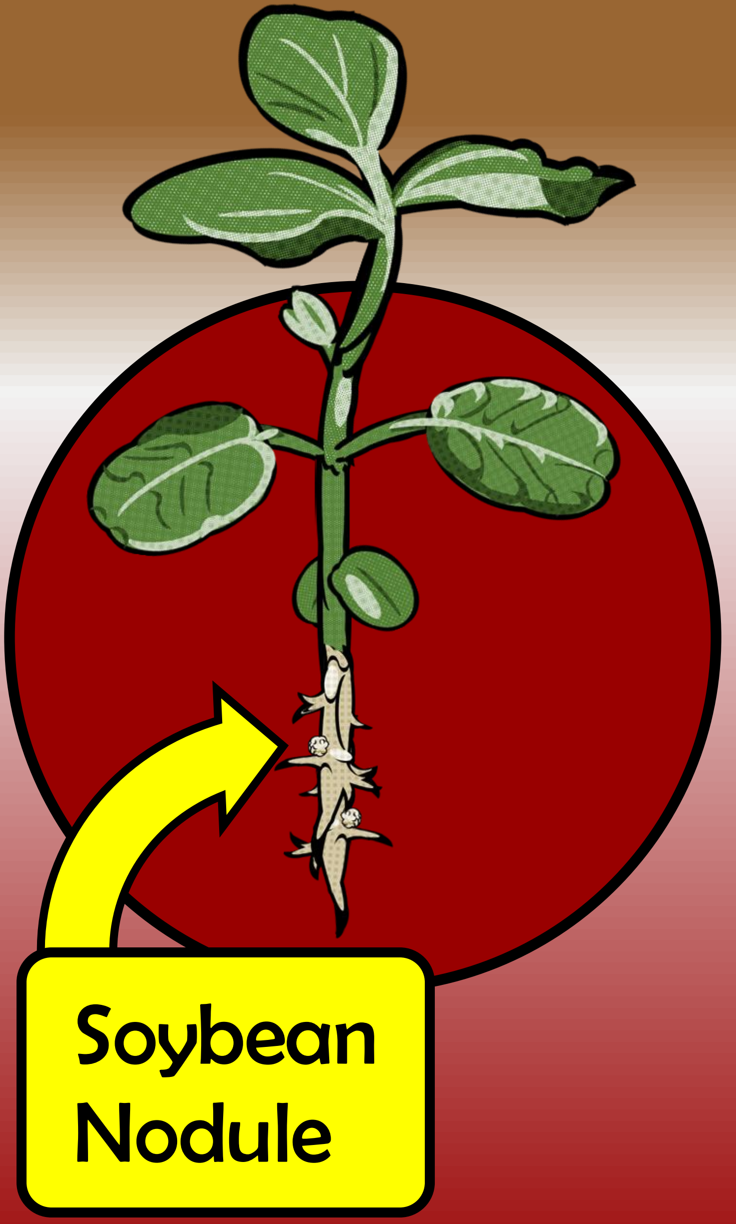
Dr. Matt Montgomery, CCA

NODULATION/ N FIXATION: INTRODUCTION

Soybean plants have a unique relationship with soil dwelling bacteria called "Bradyrhizobia," which results in the formation of "nodules." These bacteria are not native to Midwest soils. Instead, they have been introduced into local soil profiles specifically for soybean production.

Many involved in agriculture have a basic familiarity with this relationship, being aware that these bacteria "fix" nitrogen. Fixed nitrogen is then used by the soybean plant. This has historically eliminated the need for nitrogen fertilizer in beans (eliminating a significant potential cost for growers).

This storyboard series takes a deeper dive into soybean nodulation and nitrogen fixation, describing this mutually beneficial system in more detail.



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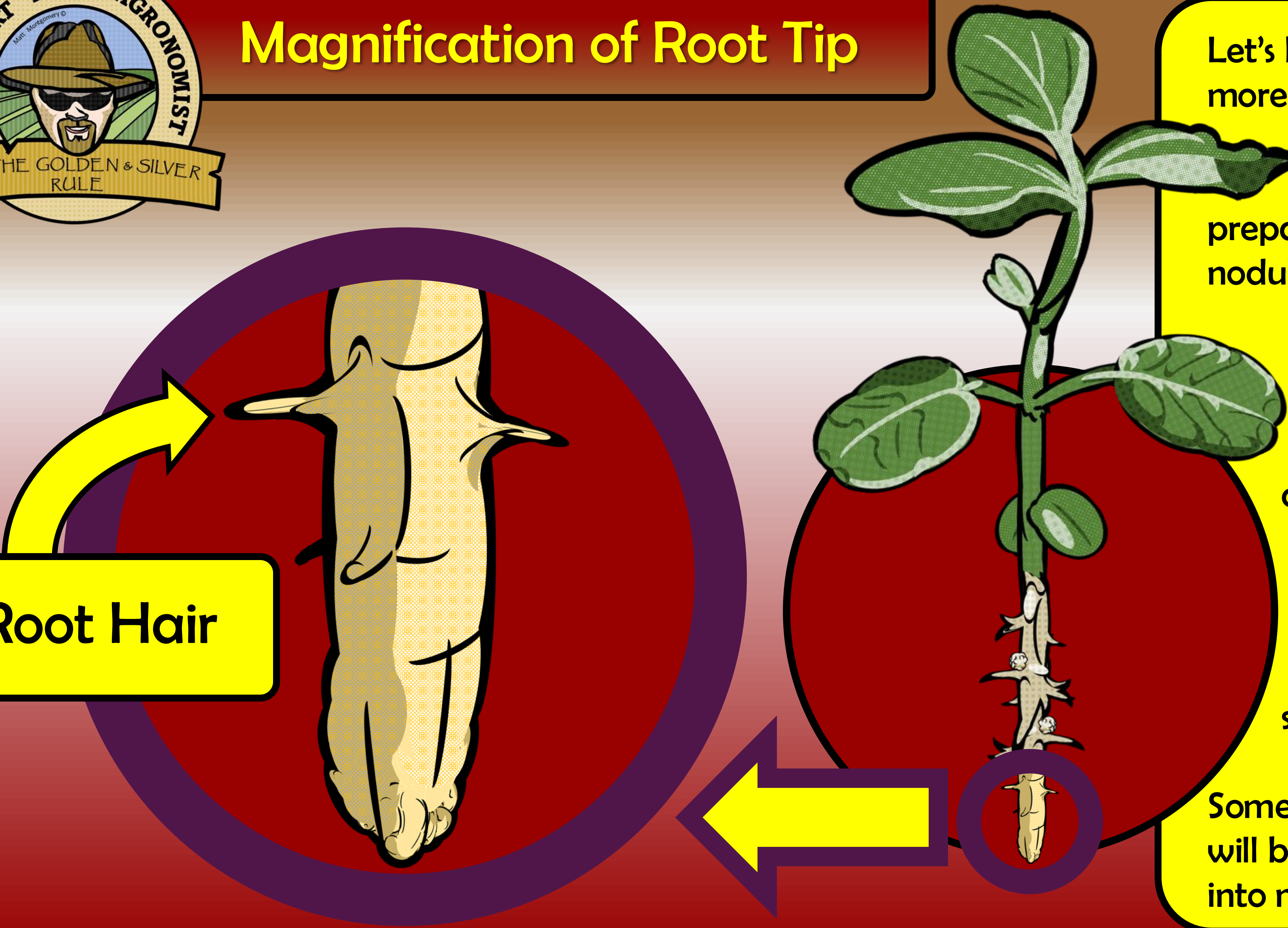
Magnification of Root Tip



Let's begin by looking more closely at the soybean root system as it prepares to develop nodules.

We are especially interested in root hairs. A common component of root systems, they allow the plant to better access soil water and soil nutrients.

Some soybean root hairs will be "transformed" into nodules.

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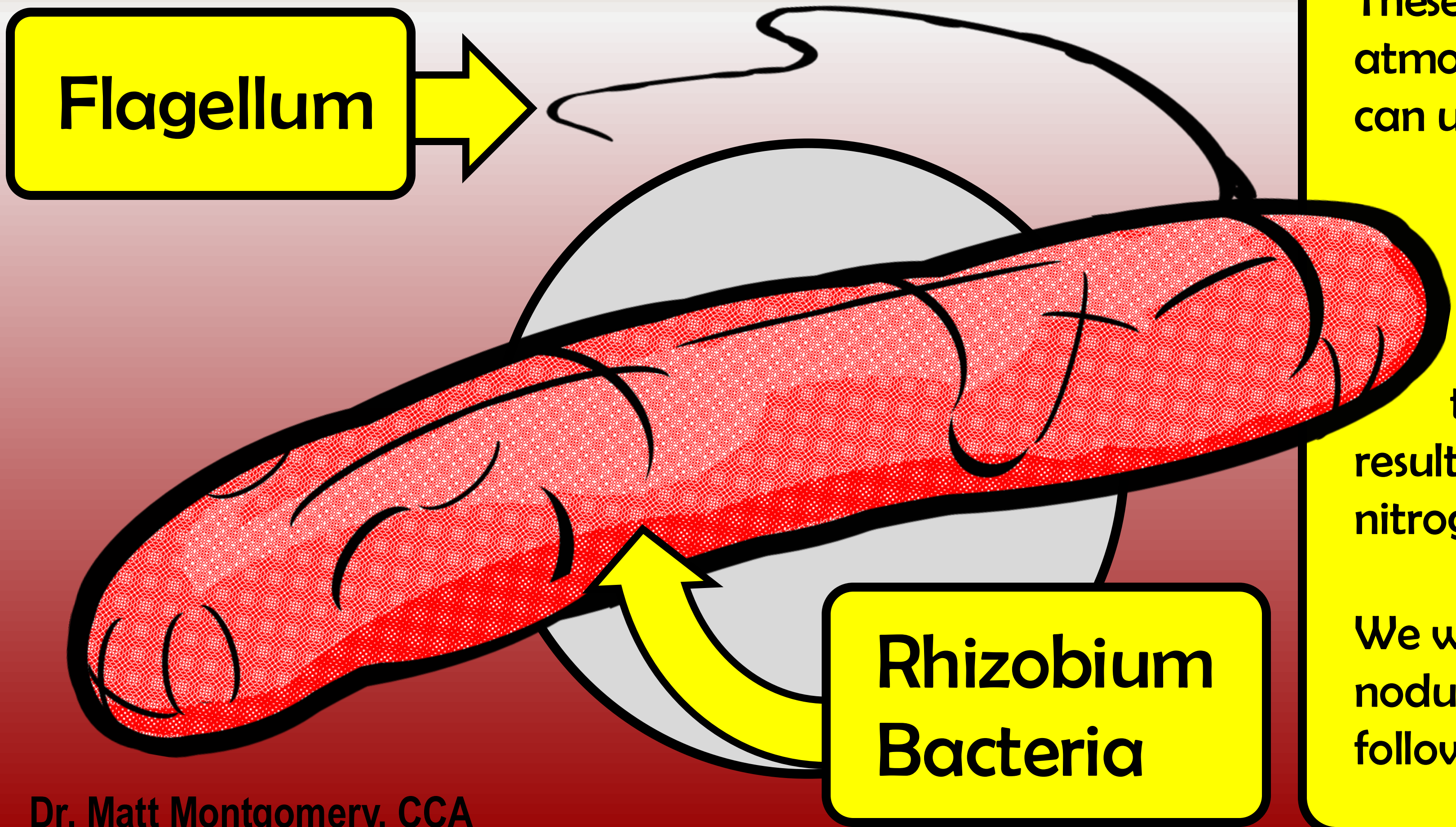
RHIZOBIUM BACTERIUM (FALSE COLOR)



How will root hairs "transform" into nodules? The transformation will take place as root hairs interact with Bradyzhizobia bacteria.

These bacteria will (as noted earlier) fix atmospheric nitrogen into a form the plant can use.

Bacteria outside the root will help initiate root hair transformation into nodules. Such bacteria will also take up residence in the core of the resulting nodule (the eventual site of nitrogen fixation).

We will further describe these bacteria and nodule formation in the sessions that follow.

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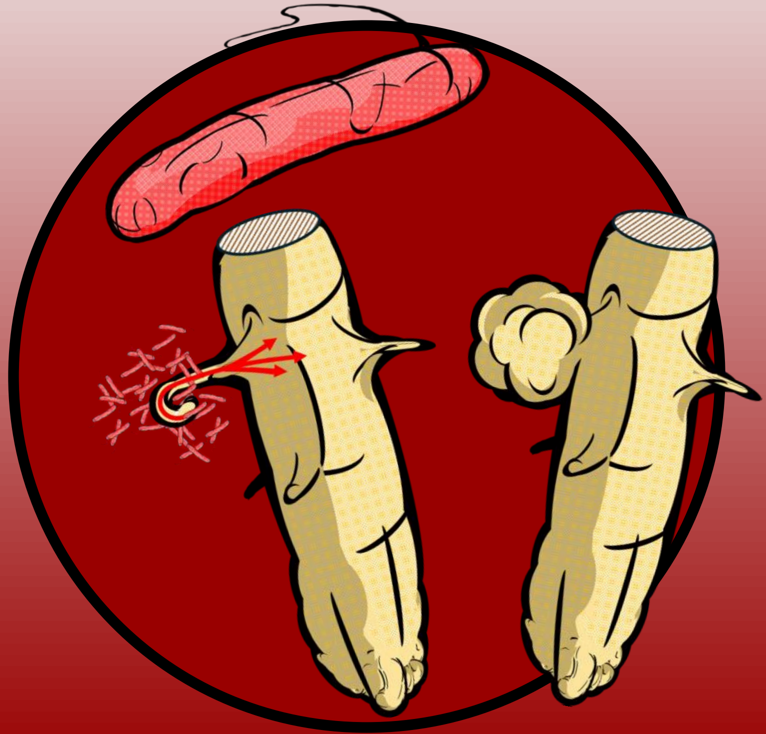
Part 2:

BRADYRHIZOBIA



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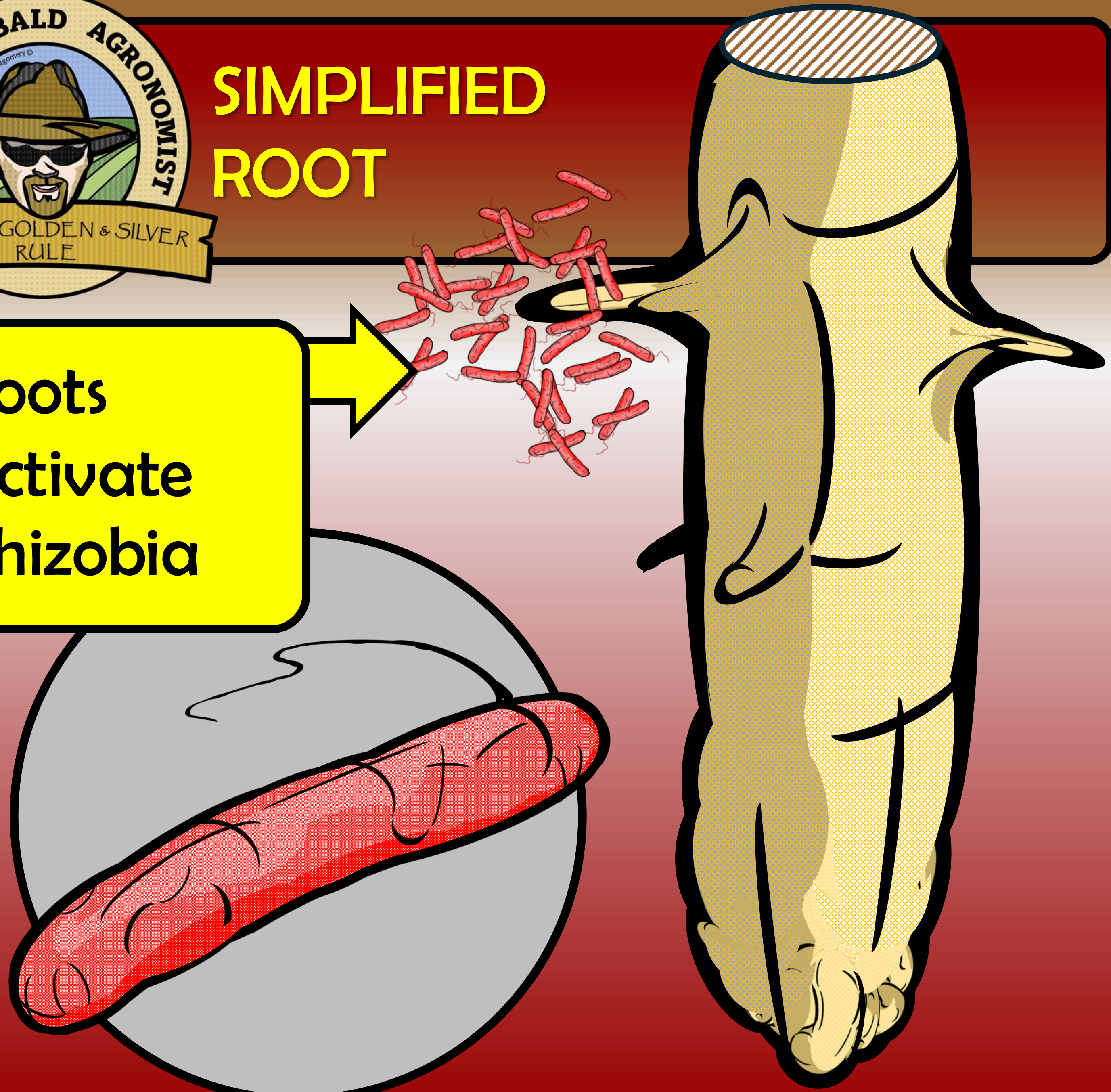
SIMPLIFIED ROOT

Roots Activate Rhizobia



Session One introduced us to two key players in soybean nodulation – root hairs and rhizobia bacteria. Let's go a little deeper in Session Two.

Rhizobia are single-celled organisms that possess a flagellum (tail for movement).

Rhizobia, introduced into fields for soybean production, lay dormant until a root hair develops nearby.

Bacteria then become active & chemically signal the nearby root hair, causing its growth and development to change.

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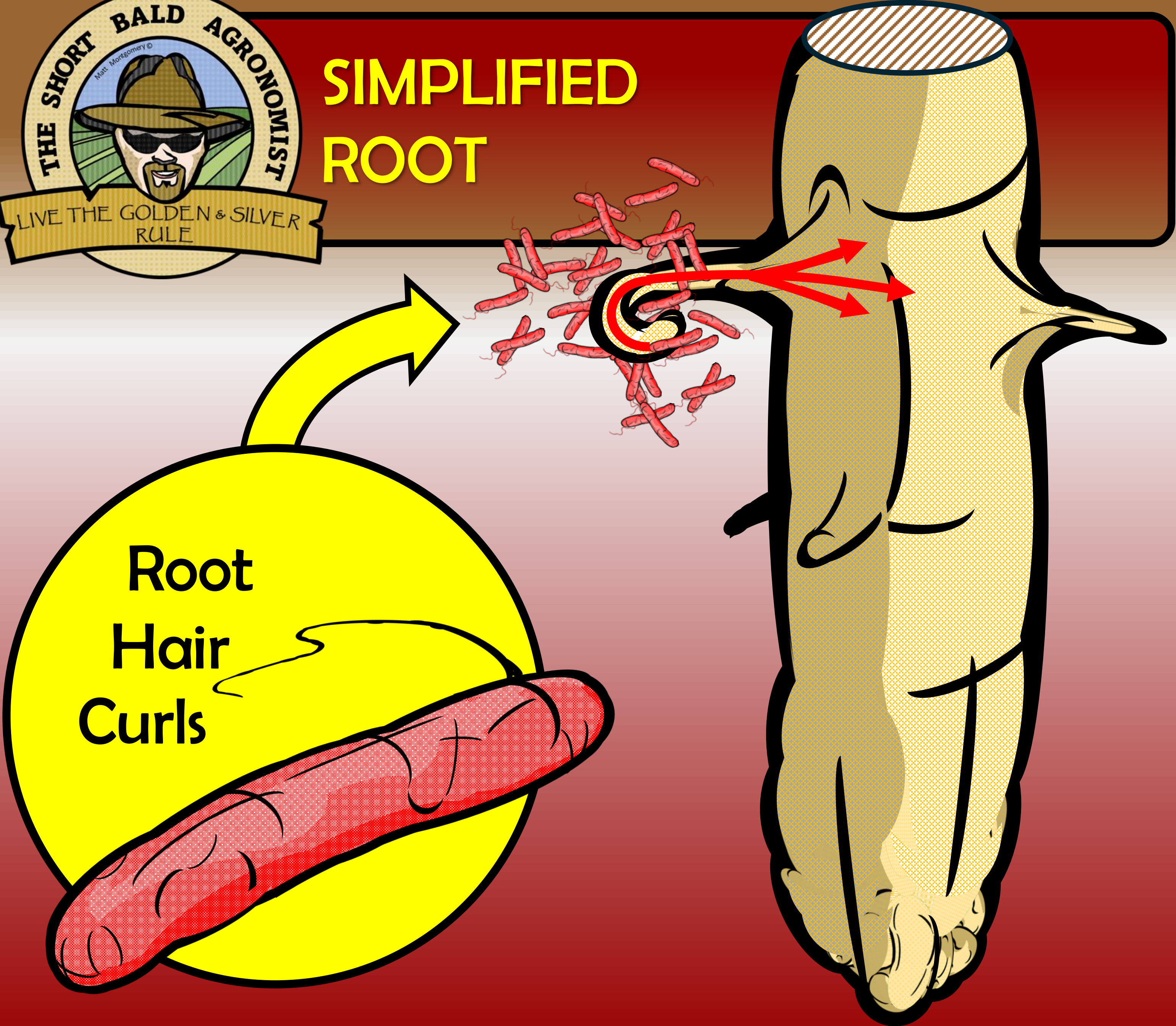
SIMPLIFIED ROOT



Root hair material will undergo many changes in response to rhizobia.

The initial change in root hair development (a plant growth regulator response) causes the root hair to curl around those “now active” soil-dwelling bacteria.

Rhizobia bacteria then enter the root hair, eventually forming an infection thread (tube-like structure).

This “infection thread” (in red) will become the “highway” for rhizobia movement into the root cortex.

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NODULATION

Root Hair Swells

Rhizobia replicate within the root cortex and initiate callous-like growth within the root. This callous growth will transform material leading up to and including the root hair, into a root nodule. This process begins around the 3-leaf stage.

Rhizobia also undergo a change. We will discuss that change in our next session.

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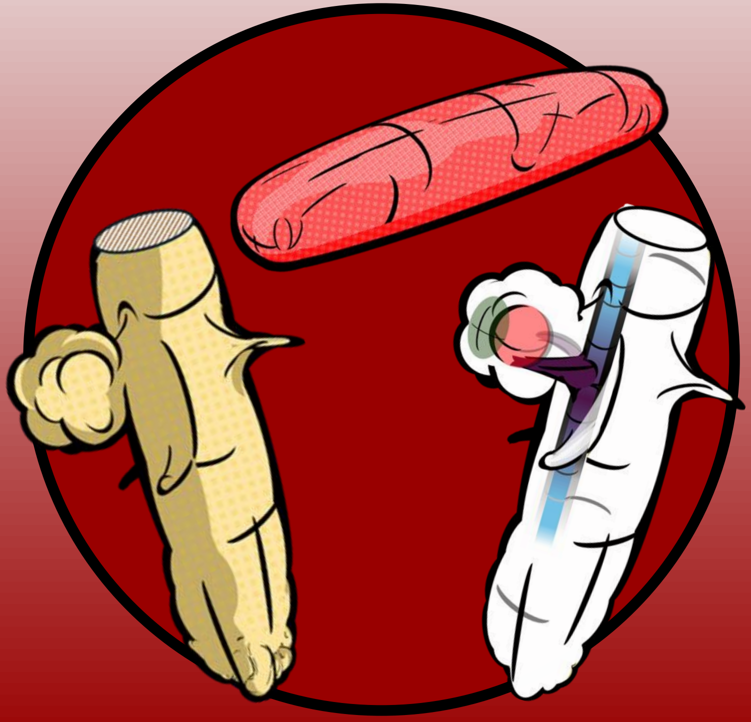
Part 3:

RHIZOBIA & NODULES (MORE DETAIL)



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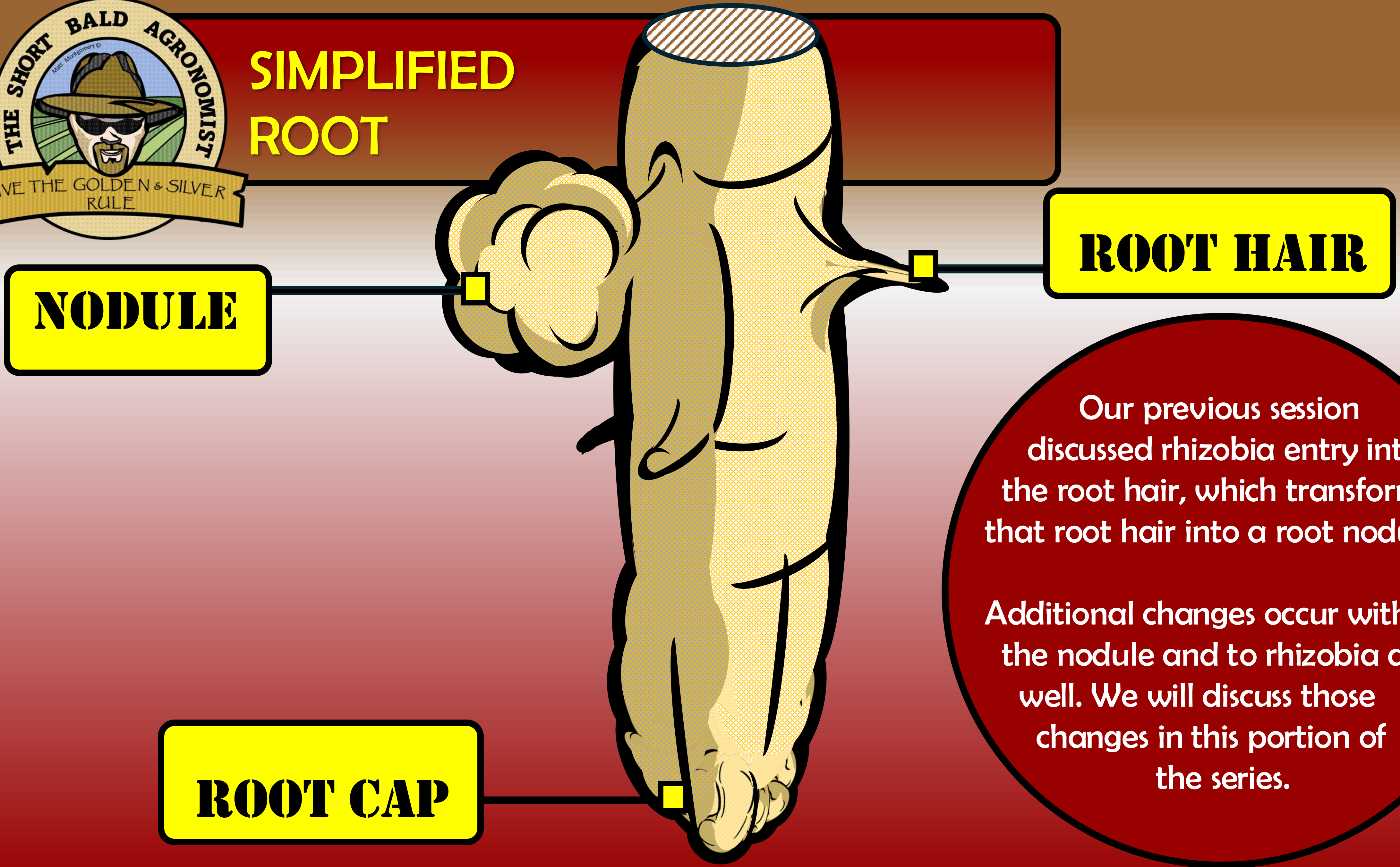
SIMPLIFIED ROOT



Our previous session discussed rhizobia entry into the root hair, which transforms that root hair into a root nodule.

Additional changes occur within the nodule and to rhizobia as well. We will discuss those changes in this portion of the series.

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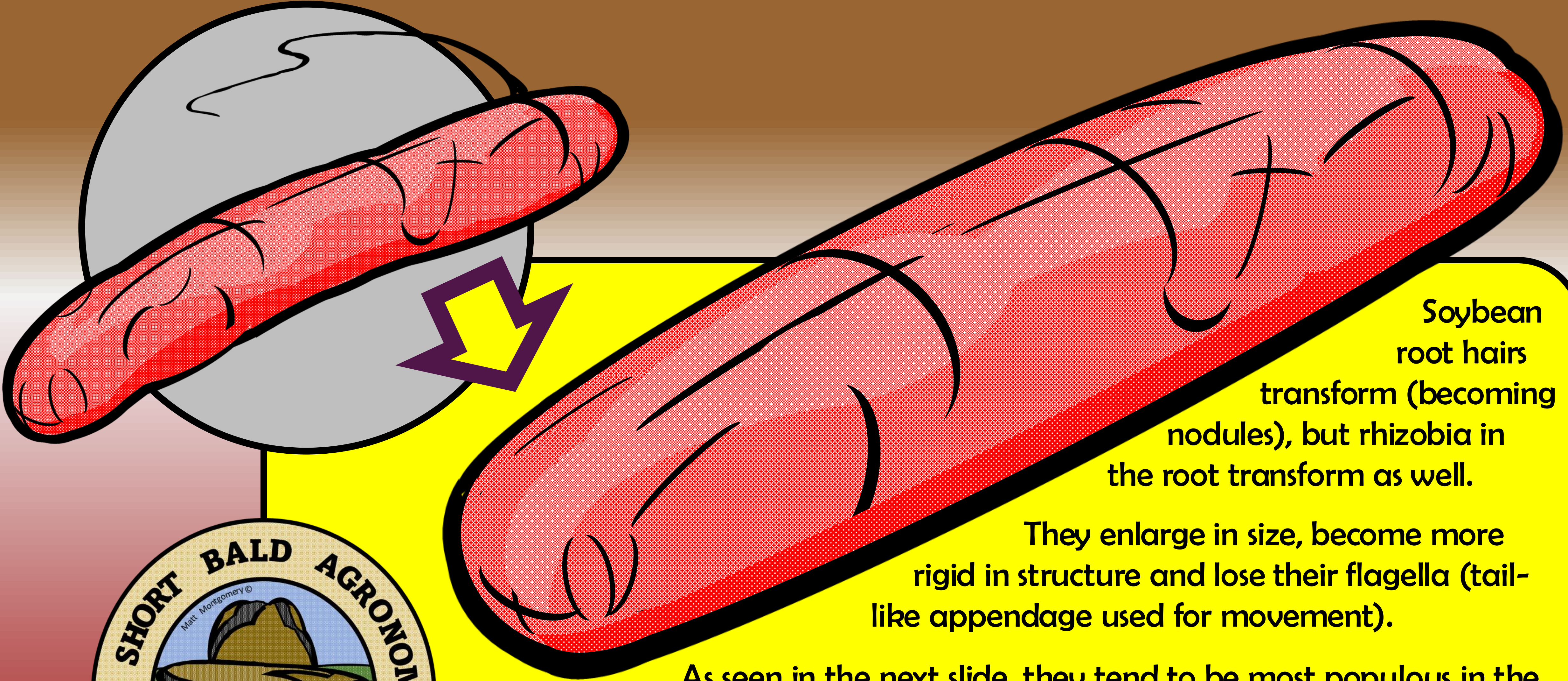

Soybean root hairs transform (becoming nodules), but rhizobia in the root transform as well.

They enlarge in size, become more rigid in structure and lose their flagella (tail-like appendage used for movement).

As seen in the next slide, they tend to be most populous in the central portion of the nodule cortex. Note the additional changes in the root as well. A brief on N-fixation is included in Session 4.

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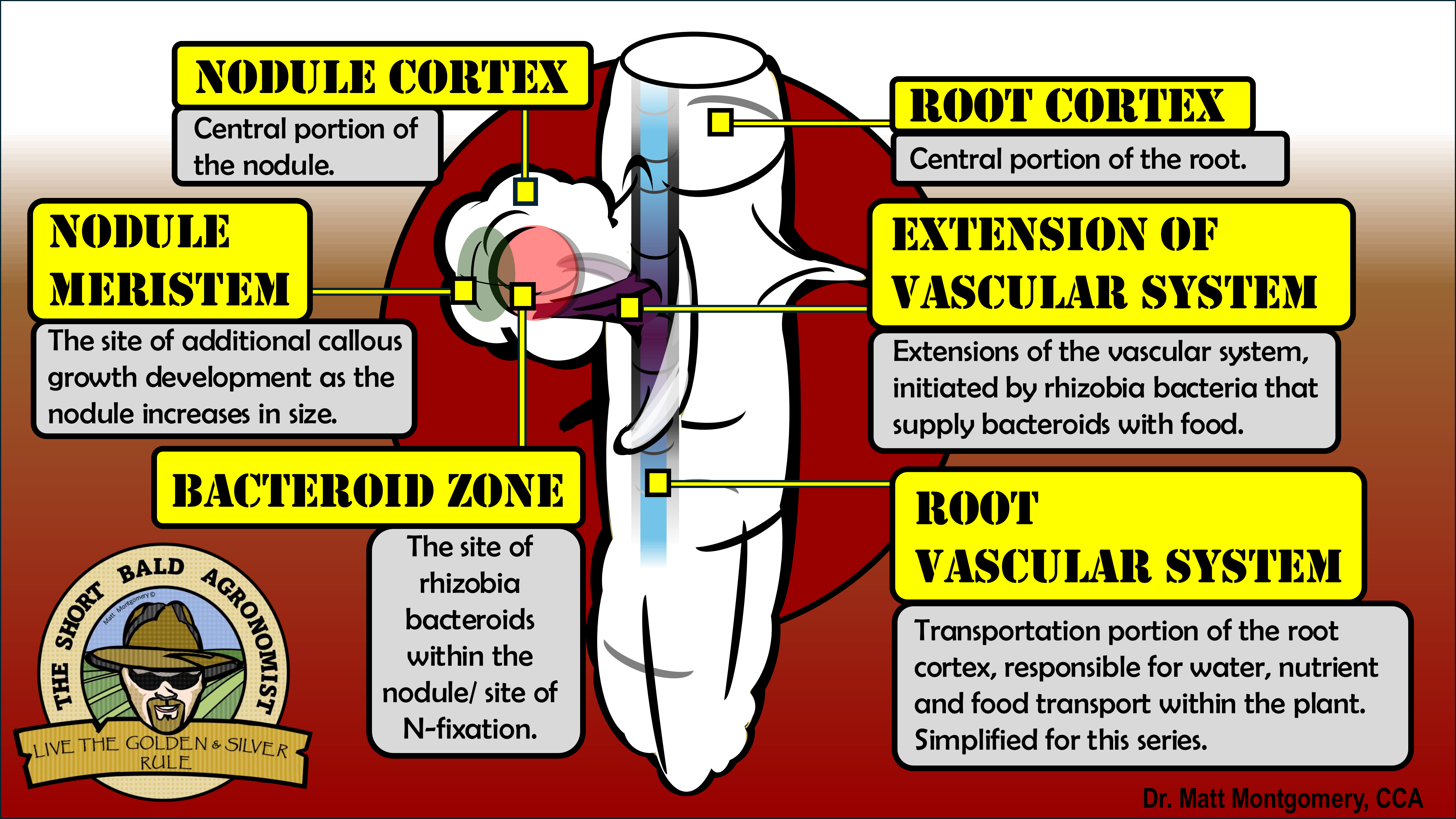
NODULE CORTEX
Central portion of the nodule.
NODULE MERISTEM
The site of additional callous growth development as the nodule increases in size.
BACTEROID ZONE
The site of rhizobia bacteroids within the nodule/ site of N-fixation.
ROOT CORTEX
Central portion of the root.
EXTENSION OF VASCULAR SYSTEM
Extensions of the vascular system, initiated by rhizobia bacteria that supply bacteroids with food.
ROOT VASCULAR SYSTEM
Transportation portion of the root cortex, responsible for water, nutrient and food transport within the plant. Simplified for this series.
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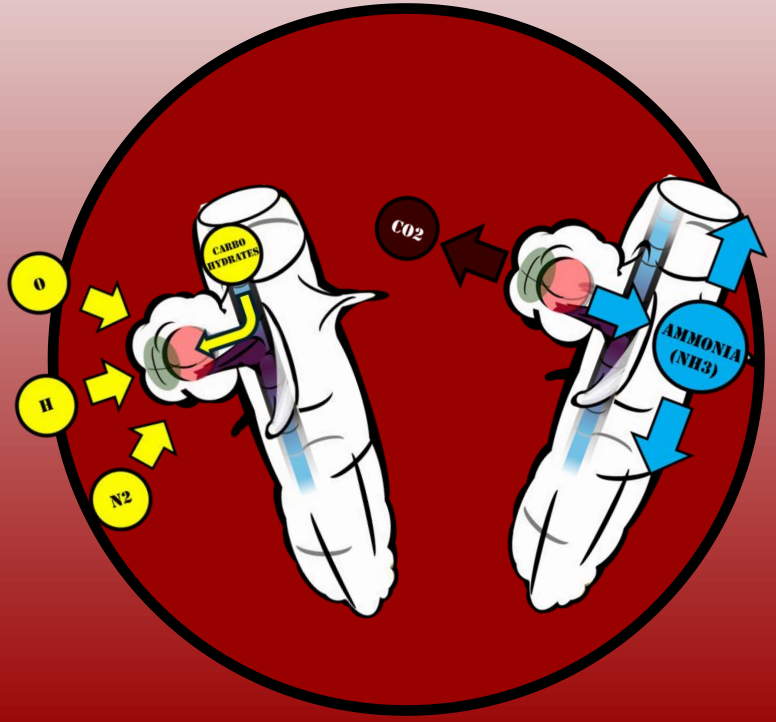
Part 4:

A BRIEF ON NITROGEN FIXATION



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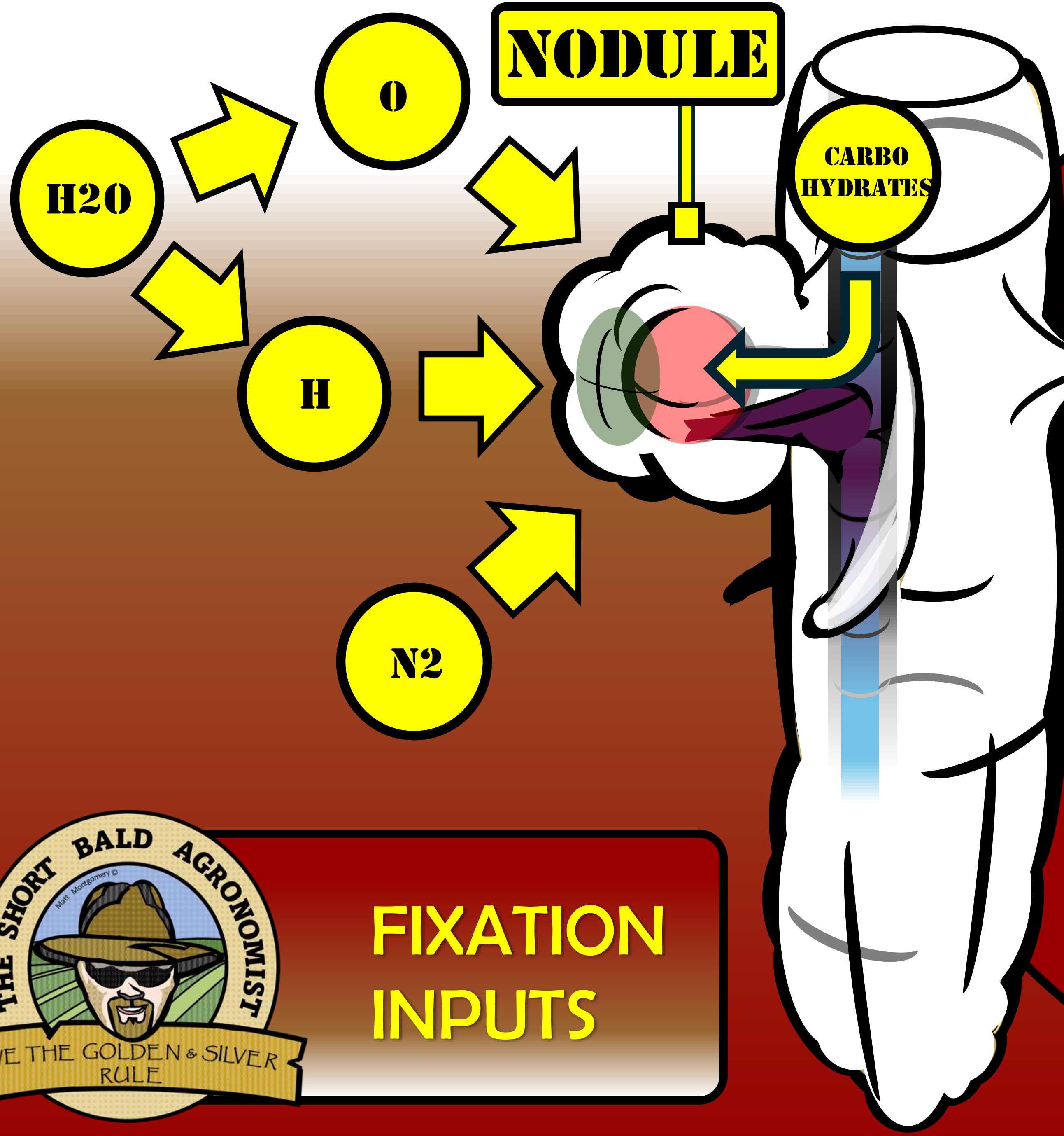

FIXATION INPUTS

We described various structures associated with root nodulation in Session 3. Let's provide a nitrogen fixation brief in Session 4.

The diagram to the left represents general "inputs" in the process.

Rhizobia bacteroids (red region) in the nodule pull in oxygen, hydrogen and atmospheric nitrogen (N2 gas).

The soybean plant feeds carbohydrates (produced via photosynthesis) to those bacteroids.

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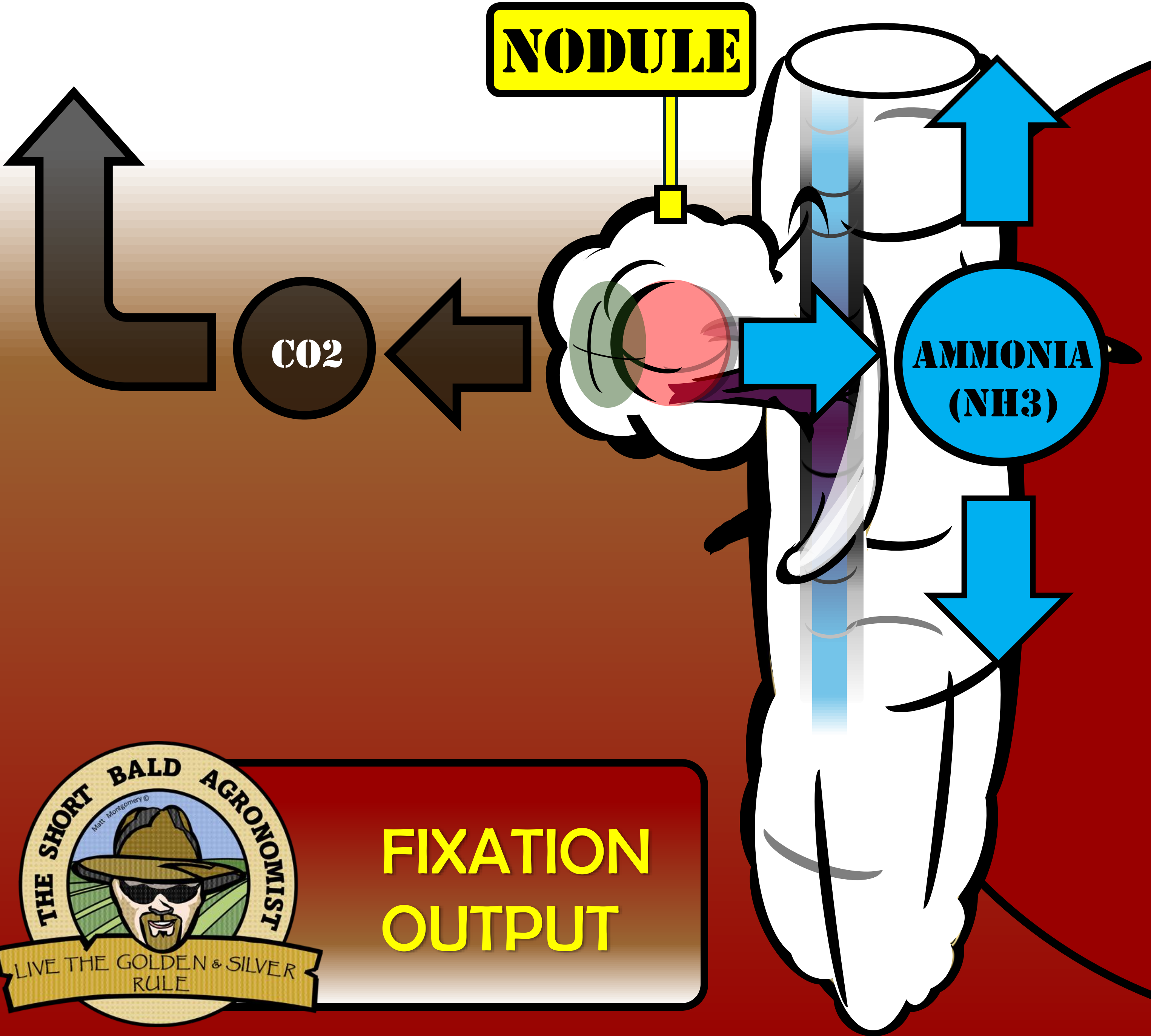
FIXATION OUTPUT



Rhizobia bacteroids, located in the central (red colored) nodule cortex take in oxygen, hydrogen, N2 gas & carbohydrates. Let's briefly reference bacteroid output.

Bacteroids take N2 gas, combine it with absorbed Hydrogen, and produce Ammonia (plant usable N).

This nitrogen is eventually redistributed via the vascular system for use by the plant.

The plant uses nitrogen to eventually produce amino acids – basic structural building blocks.

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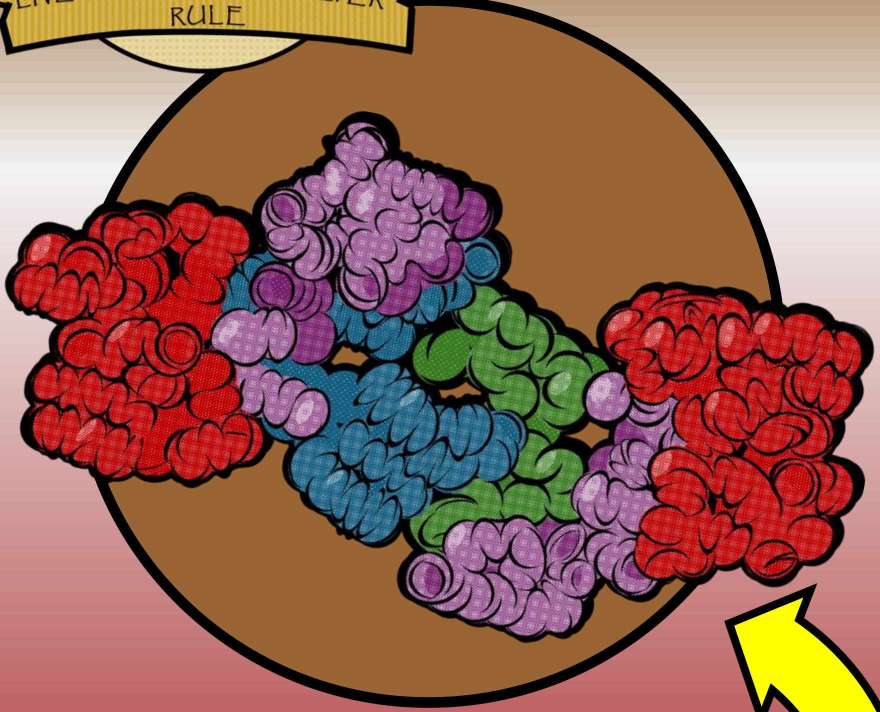
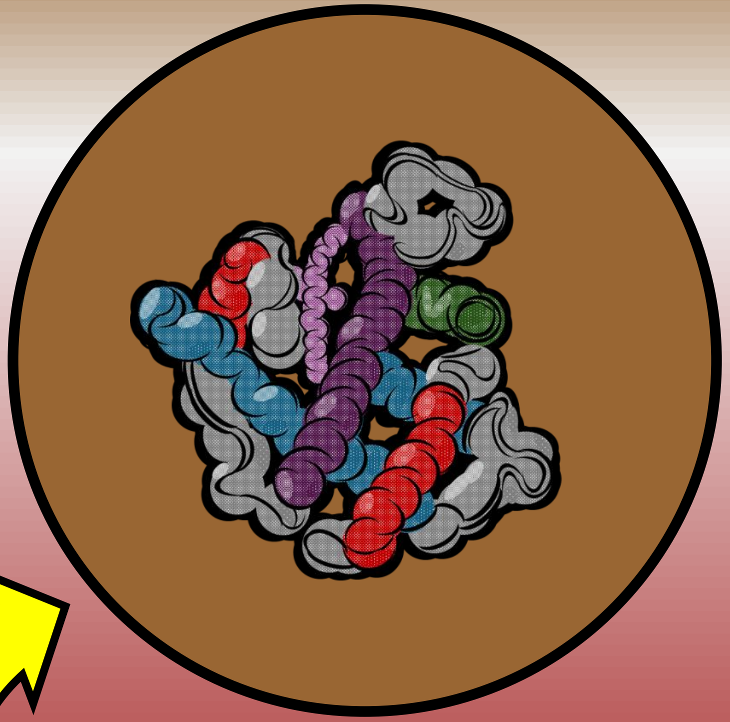
TWO KEY COMPOUNDS INVOLVED IN N-FIXATION



Session Five will describe nitrogen fixation in a little more detail.

That session will note two key compounds associated with the nitrogen fixation process.

Those compounds are termed nitrogenase and leghemoglobin.



NITROGENASE

(THE N-CONVERSION ENZYME)

BACTEROID-DERIVED

LEGHEMOGLOBIN

(NITROGENASE PROTECTING)

PLANT & BACTEROID-DERIVED

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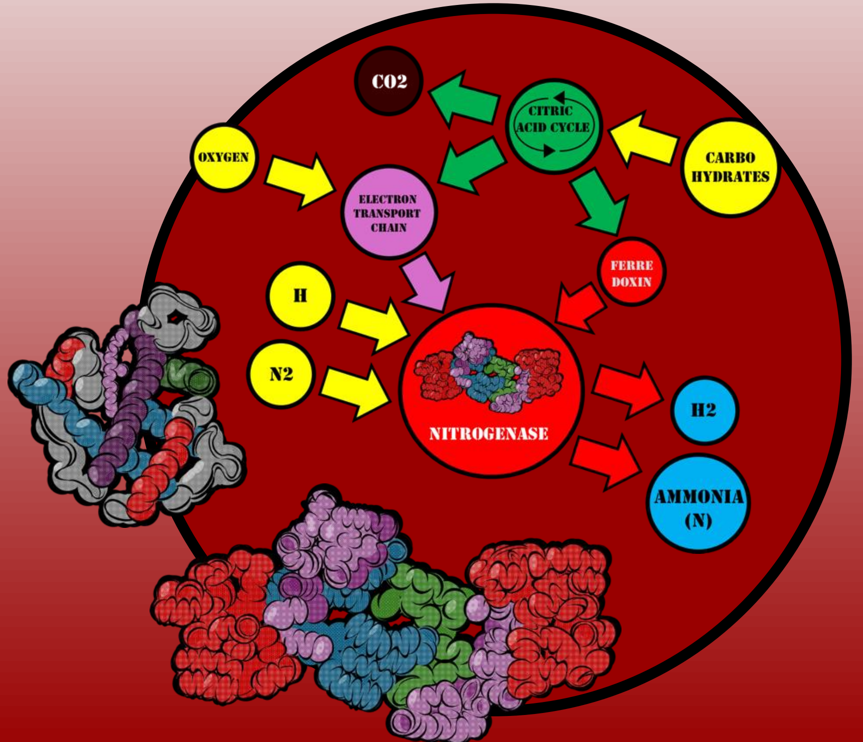
SOYBEAN NODULATION & NITROGEN FIXATION

Part 5:

N FIXATION (MORE DETAIL)



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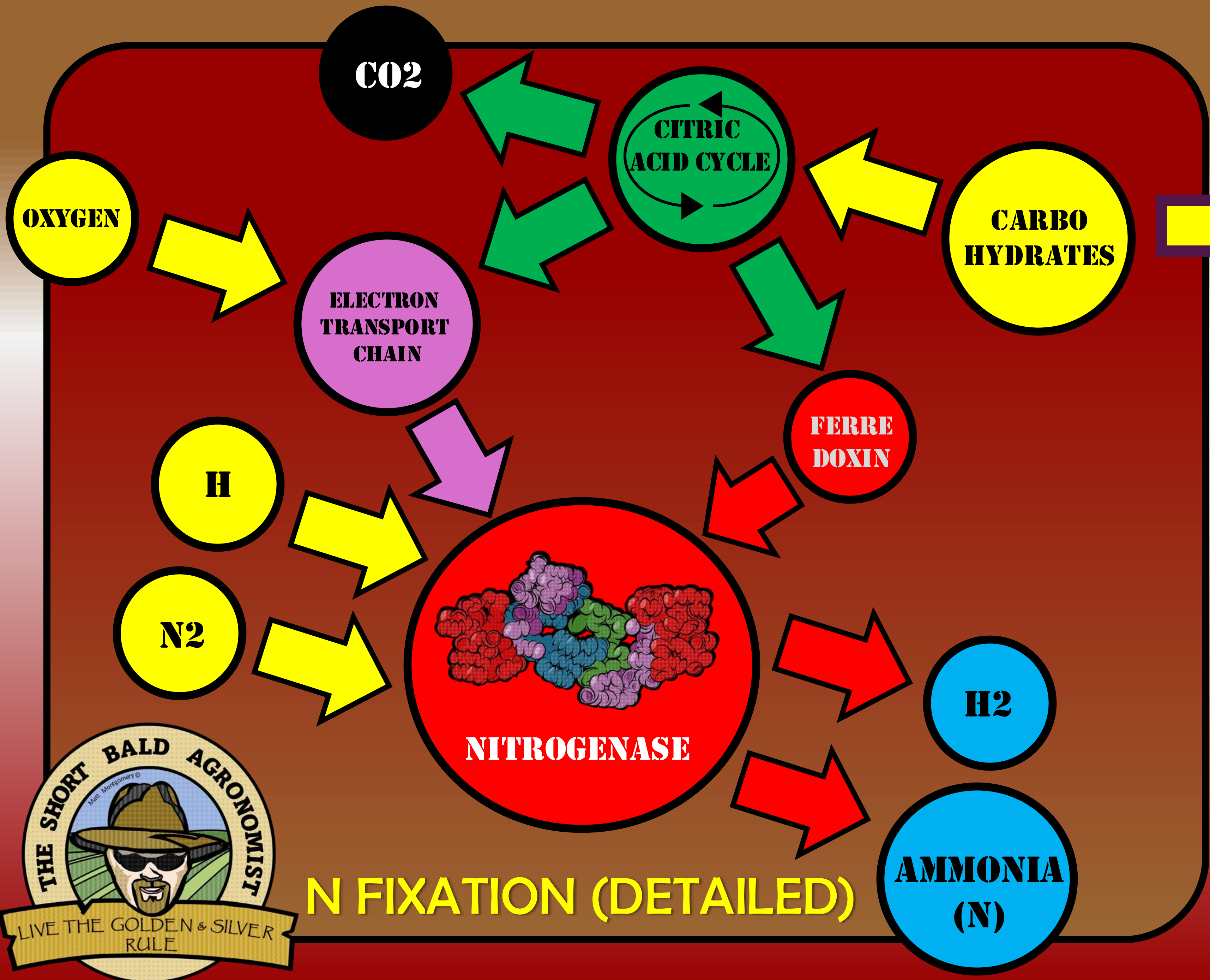
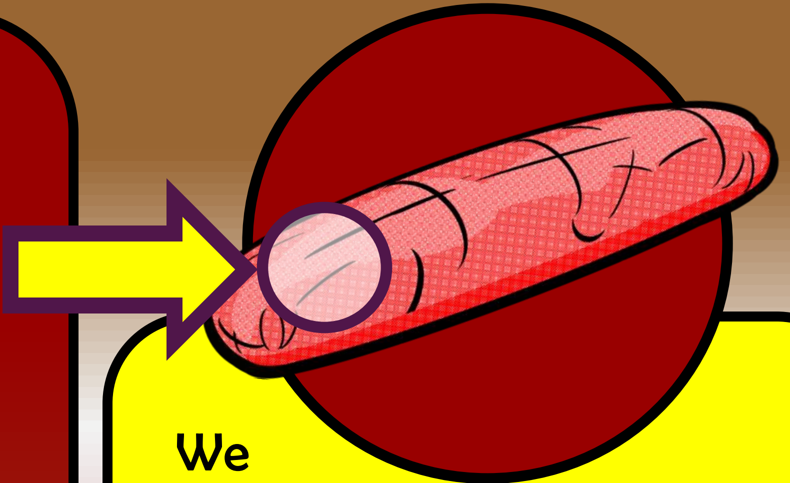
N FIXATION (DETAILED)





We promised more detail…

Rhizobia bacteroids (above) use the Citric Acid Cycle to break down plant-supplied carbohydrates (top right).

The resulting material fuels respiration (in purple - the energy harvesting process – necessary to keep Rhizobia alive).

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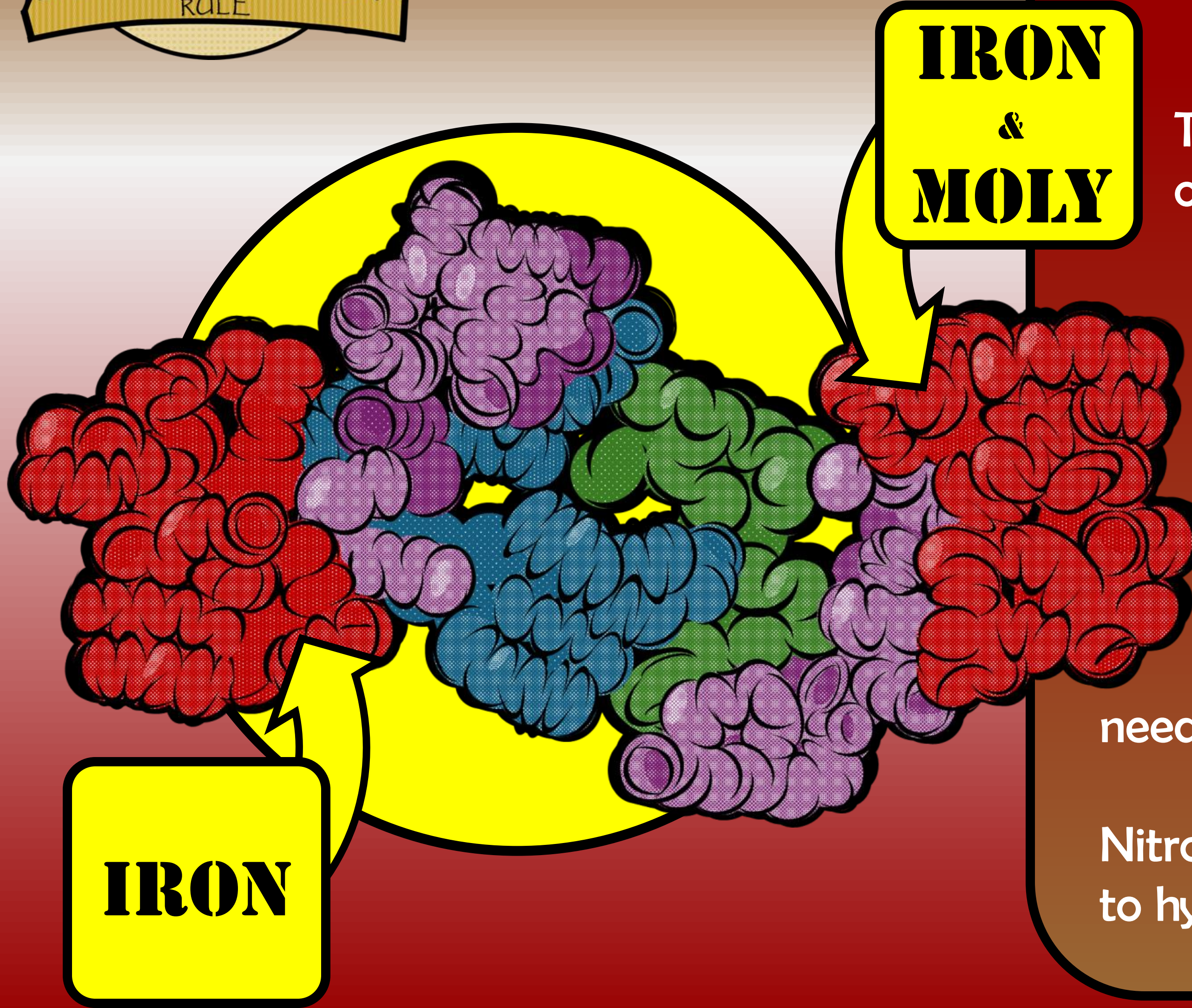
NITROGENASE
(The N-Conversion Enzyme)



The energy harvested from respiration is used to keep rhizobium alive, but it also is used to fuel activity in the enzyme on the left of the page.

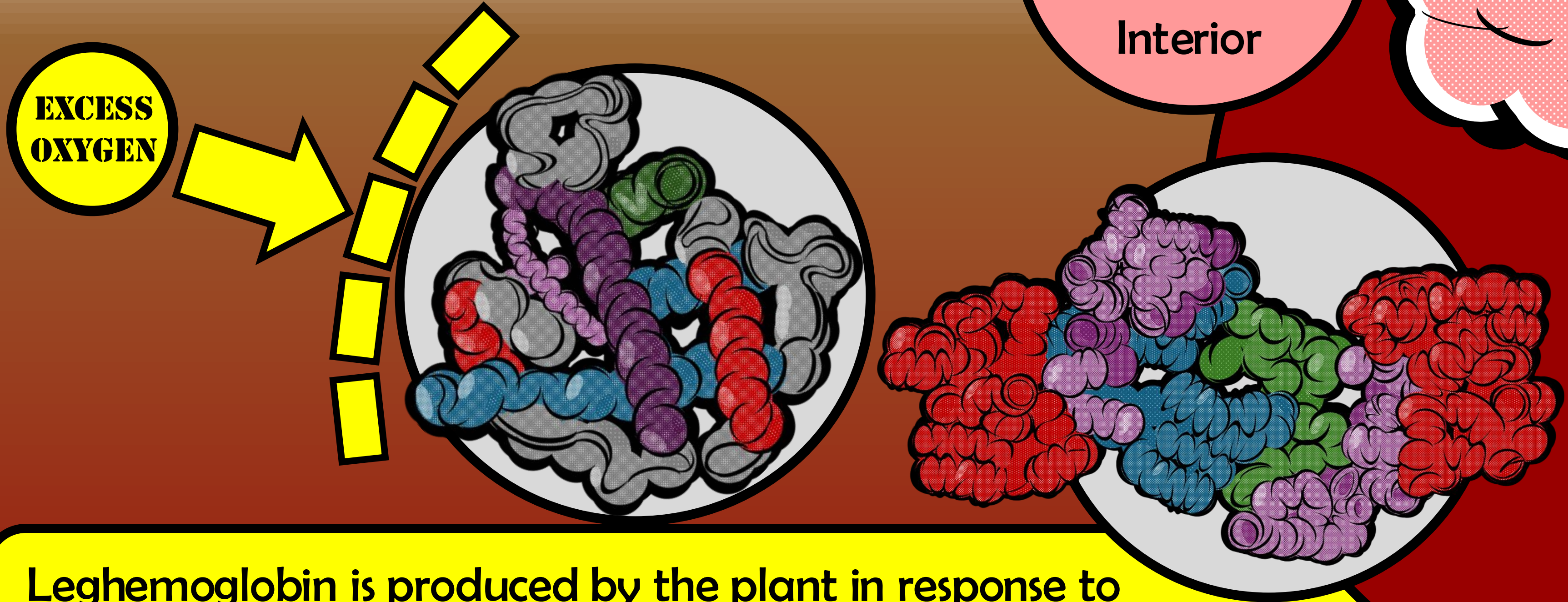
The enzyme is termed nitrogenase, and it uses a lot of energy.

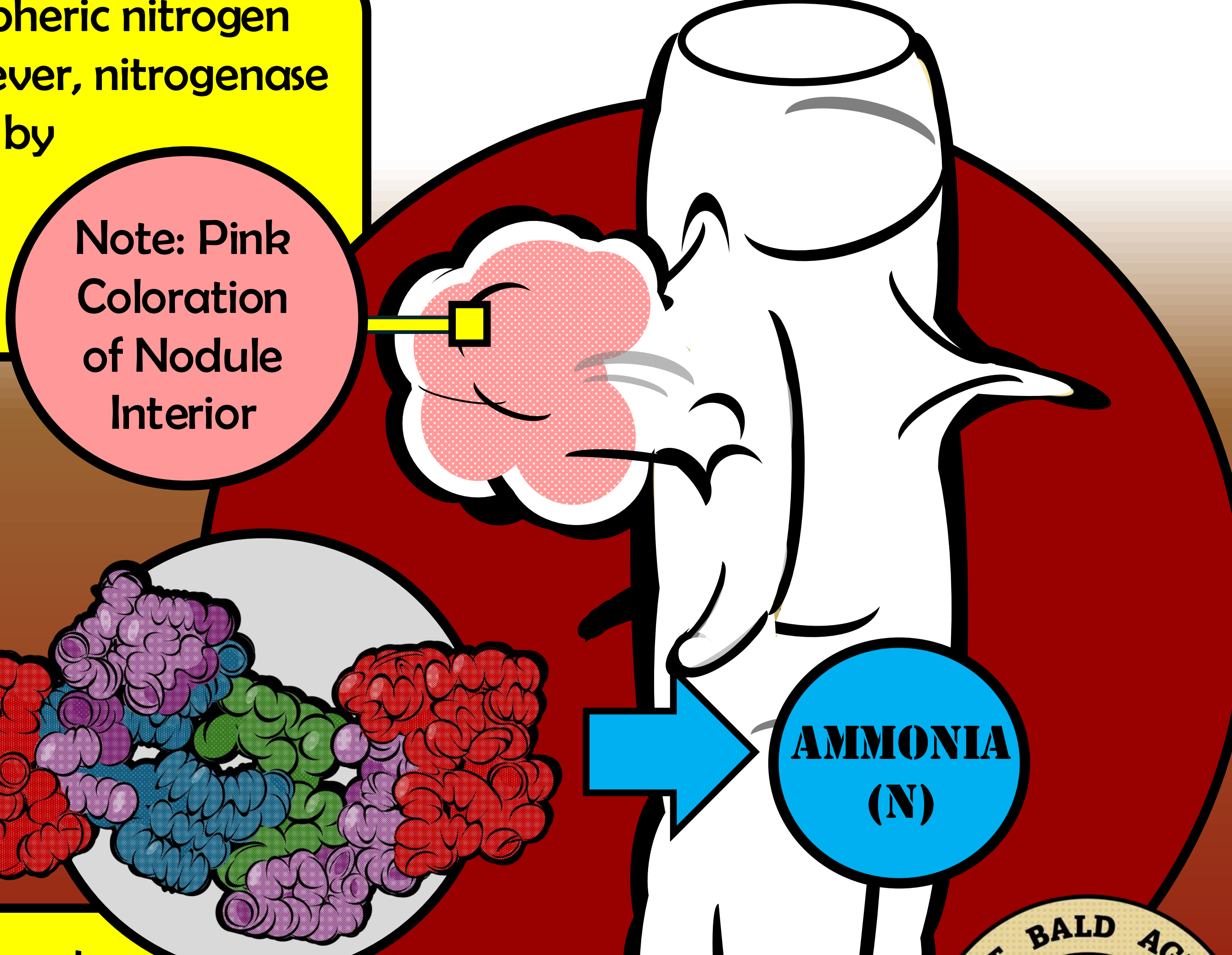
Nitrogenase is a large, and somewhat complex molecule – with one pole consisting of iron and the other consisting of iron and molybdenum.

This “energy conduit” facilitates the splitting of N2 gas (a very impressive accomplishment given the fact that the energy in a lightning bolt is needed to otherwise break that bond).

Nitrogenase then uses more energy to bind that nitrogen to hydrogen, creating ammonia (fixed N).

Nitrogenase is the key enzyme used to fix atmospheric nitrogen into a form the plant can use (Ammonia). However, nitrogenase has a weakness. It fails to function if surrounded by too much oxygen. Something must shield nitrogenase from excess oxygen, and that something is called "leghemoglobin."





Leghemoglobin is produced by the plant in response to the presence of rhizobia. It is responsible for the pink coloration within the soybean nodule, and it captures excess oxygen. This allows nitrogenase to function in its needed low oxygen environment and explains why a lack of pink makes a nodule inactive (non-N-fixing).

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