Nitrogen dynamics in the Caatinga

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Main topics to be discussed

Introduction about Caatinga

N stocks and impacts of land use and climate change

N cycling and management strategies in low input systems

Guiding questions

Summary and conclusions

Description of the Caatinga ecosystem

Source: http://siscom.ibama.gov.br/monitorabiomas/

Land cover in the Caatinga Biome	Area (Millions ha)	%
Native vegetation	44,1	53,38
Deforested area (pastures and agriculture)	37,9	45,92
Water	0,83	1,01
Total	84,44	100

Same area of Germany and Spain combined

Population: about 25 million people

Land tenure: Majority of farms smaller than 10 ha

Lowest human development index in Brazil

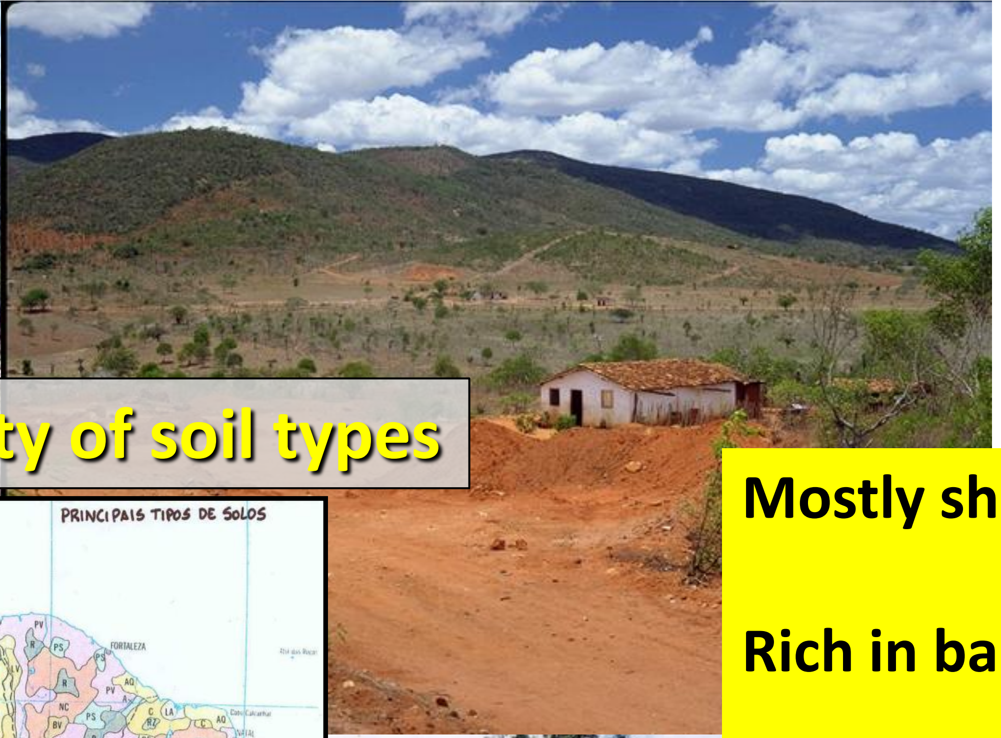
High variability of rainfall precipitation

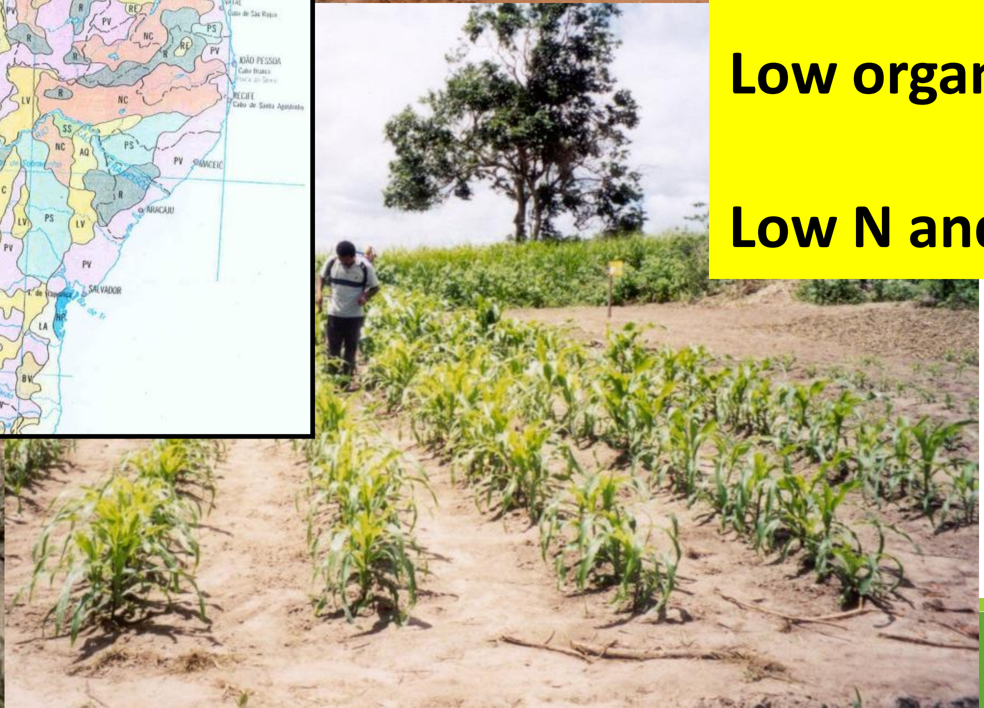
Average annual precipitation: 300 to 800 mm in different areas of the region;

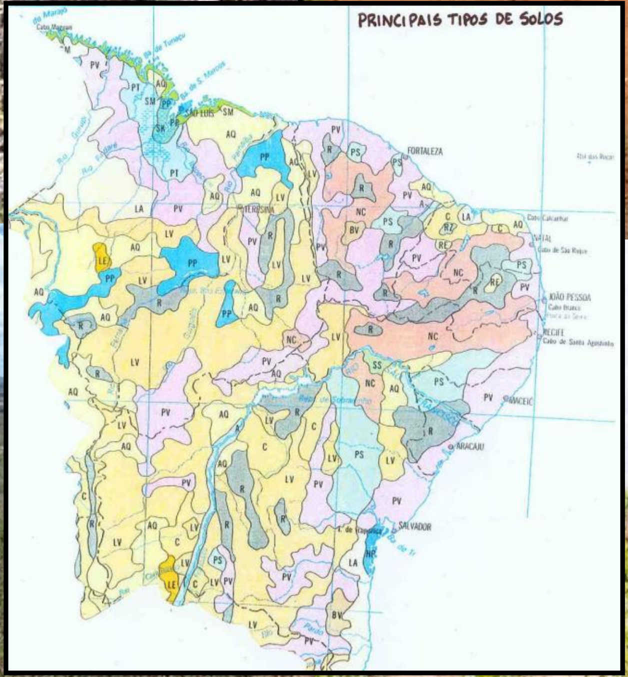
On average, 60% of the rainfall in one month, while 30% happens in a single day;

In the long term: Severe droughts have occurred every 10 to 15 years.

High variability of soil types







Mostly shalow soils

Rich in bases (K, Ca, Mg)

Low organic matter

Low N and P availability

Main land use types in the Caatinga Biome

Subsistence agriculture (maize, beans and cassava)

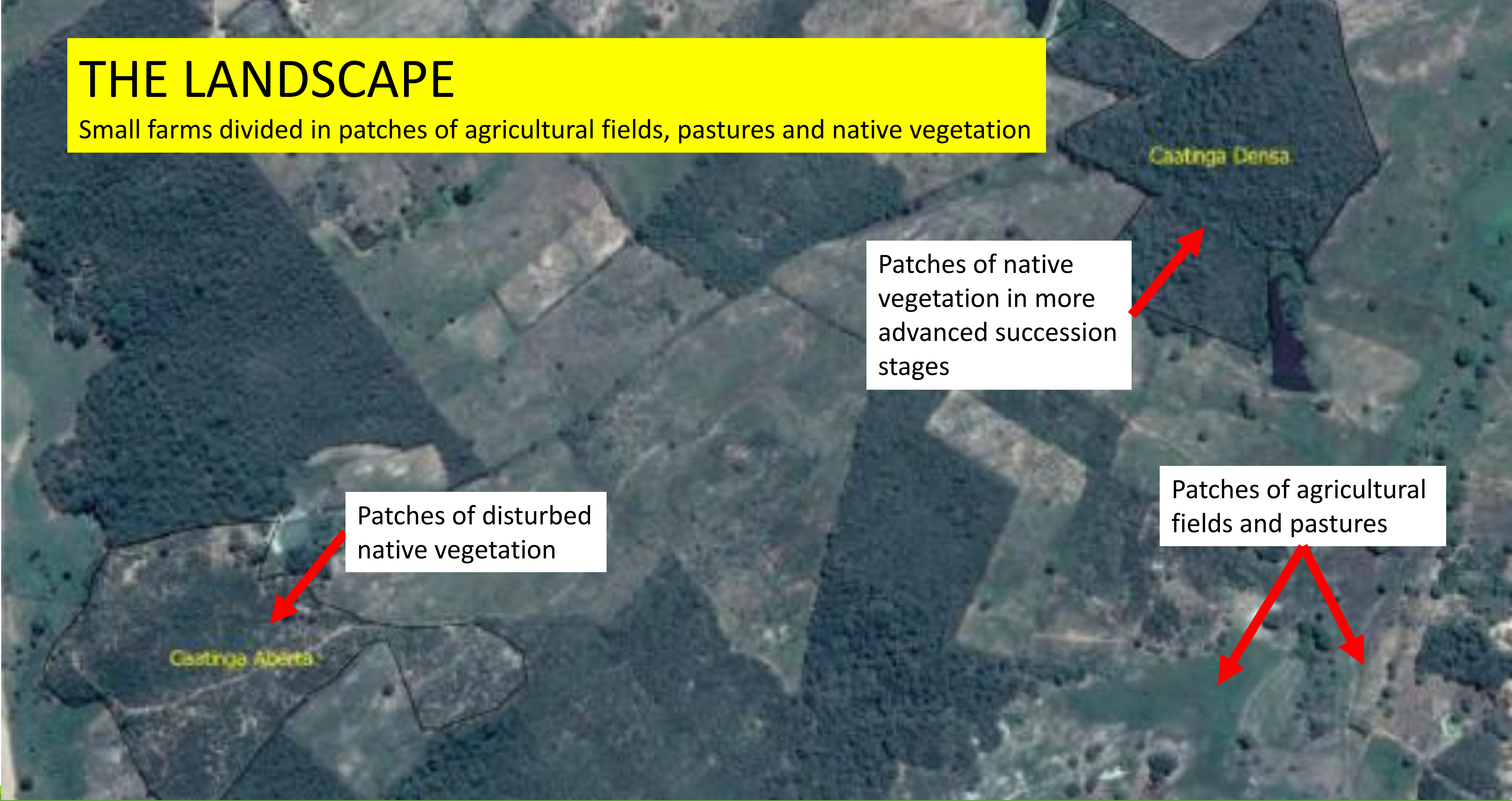
Livestock production (cattle, goats, and sheep grazing on caatinga vegetation)

Wood extraction from caatinga




THE LANDSCAPE

Small farms divided in patches of agricultural fields, pastures and native vegetation











Mature, well preserved caatinga vegetation (Patos, PB)

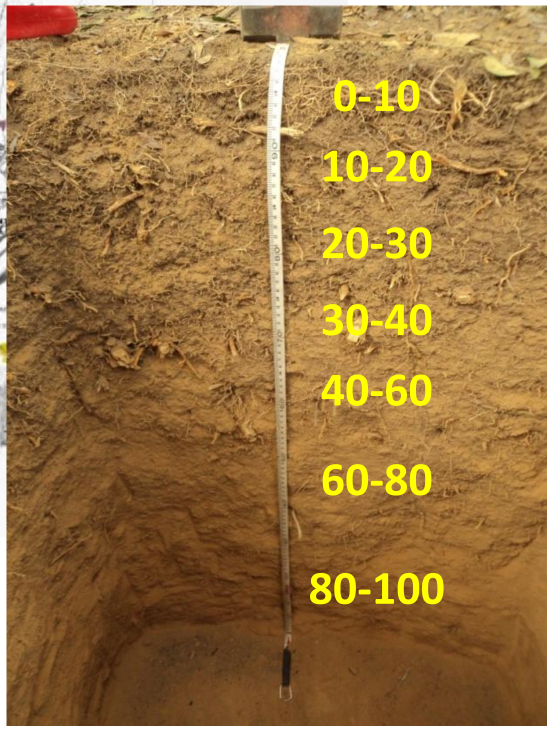
Soil N stocks in the top layer(0-20 cm) in diferent Brazilian ecosystems

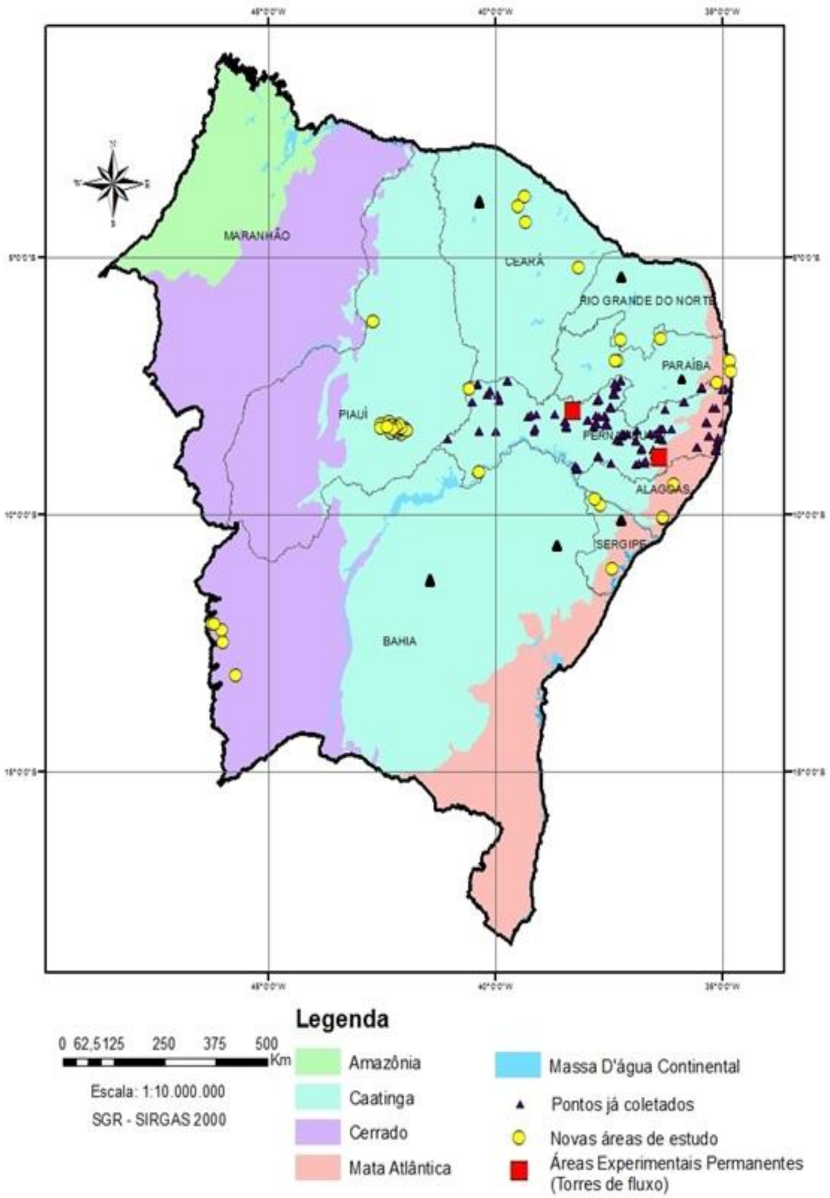
Biome	Soil N stocks in top layer (t ha^{-1})
Mata Atlântica	14-20
Cerrado	4,6
Caatinga	2,5

Source: Martinelli et al., 2014 (Chapter 5, PBMC, 2014)

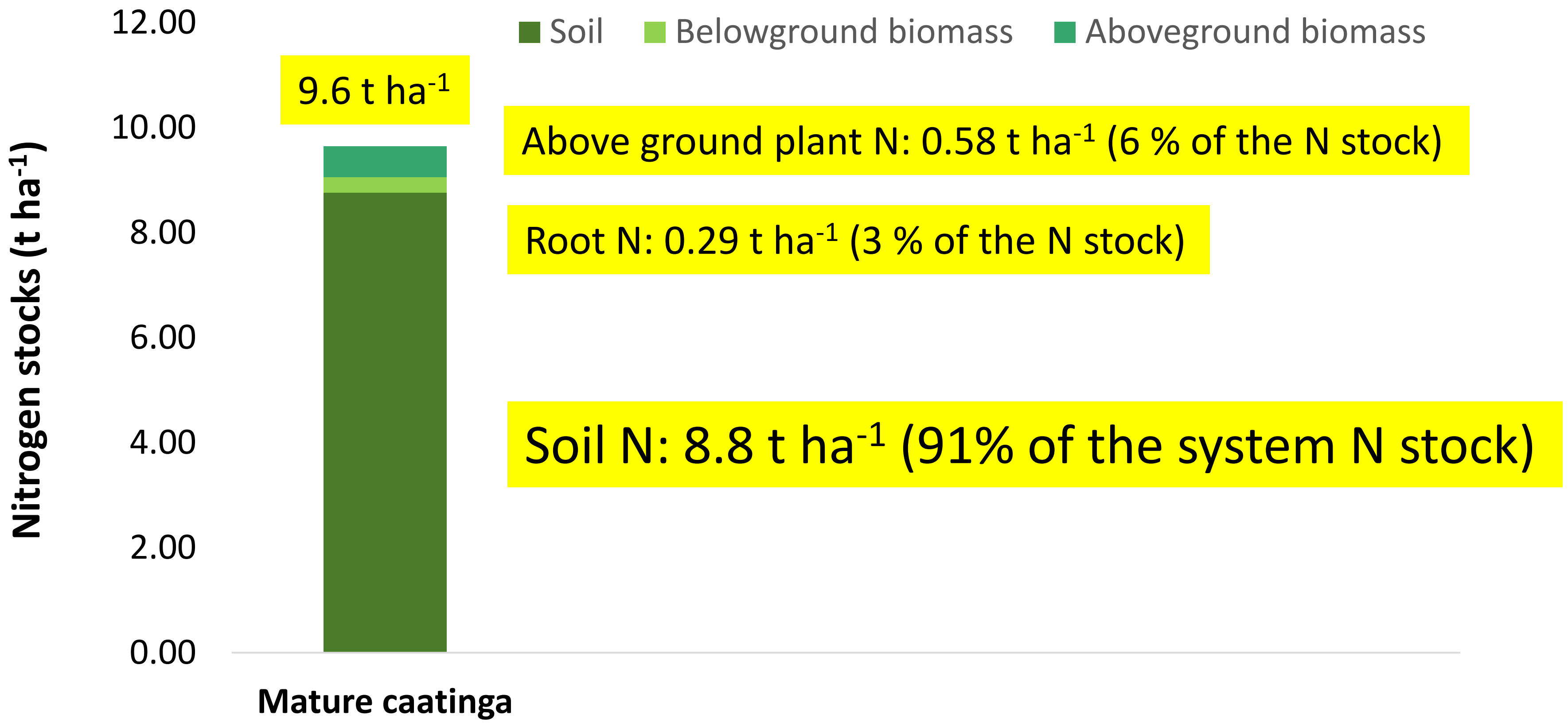
Lower stocks in Caatinga compared to other ecosystems

Quantification of C and N stocks in caatinga-study sites

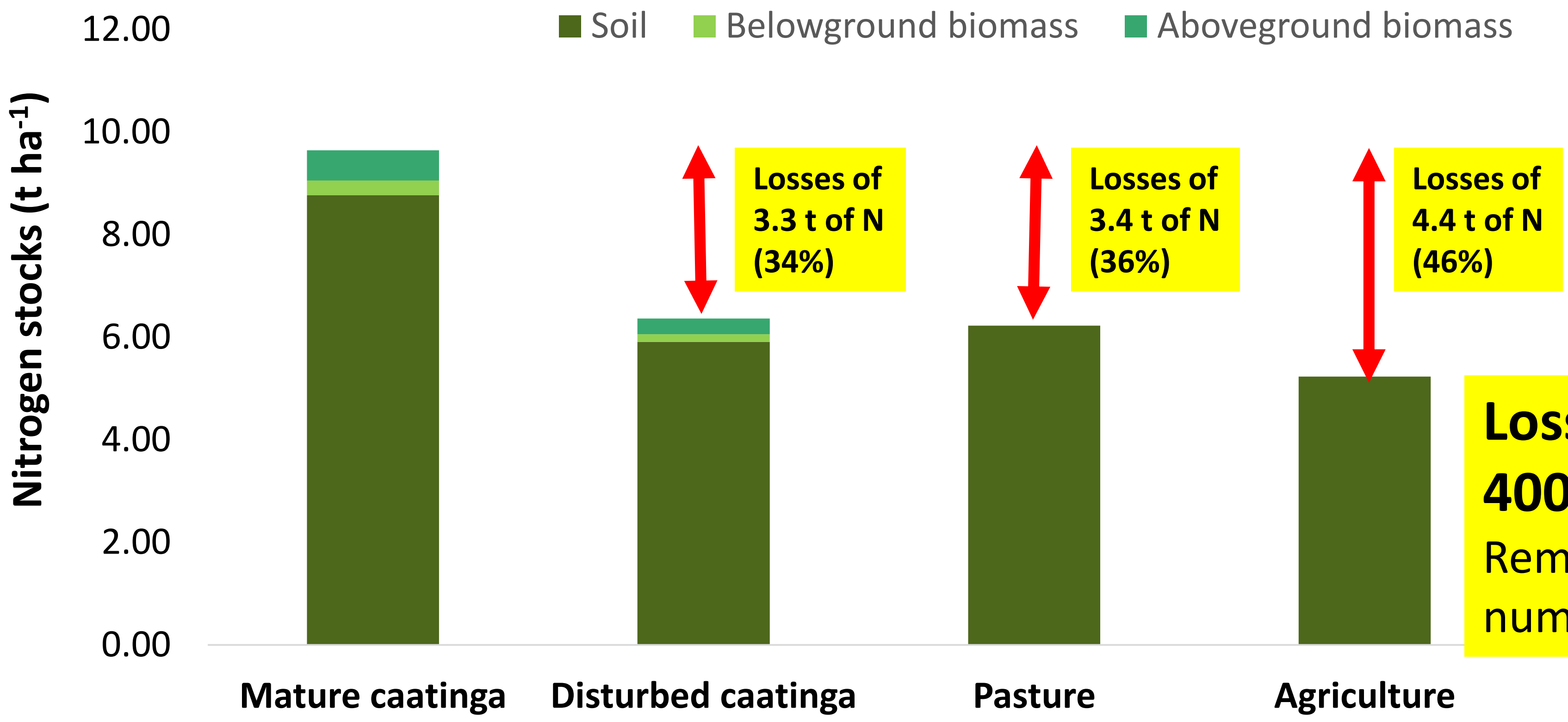




Nitrogen stocks in a “preserved” Caatinga site
(mature, dense native vegetation, 0-100 cm soil layer)



Nitrogen stocks in different land use systems in the Caatinga (0-100 cm soil layer)



Losses of 3000 to 4000 kg N ha^{-1}

Remember these numbers!!

Drivers of land use change and N dynamics

An important driver for N fluxes in the caatinga: grazing



The "leather civilization"

The importance of livestock production in the caatinga







Livestock expansion in the Caatinga

Sugarcane cultivation in the humid coastal area since the 1600's

- Portuguese crown prohibition of cattle in the sugarcane area
- High demand for leather and meat
- Availability of large areas of range suitable for cattle in the Caatinga region
- Land leasing from the crown and labor arrangements with "vaqueiro" system

Typical farmhouse in the caatinga

With the corral next to the house

Casa da Fazenda Saco dos Pereiras (Acary - RN), mostrando a arquitetura mais comumente utilizada na construção das habitações rurais do Seridó

The importance of cattle in the Caatinga

Livestock production, due to the pattern of colonization of the region, is a very importante activity, both from the cultural and socioecnomic point of view.

For this reason, today we observe very high animal stocking rates in most of the region (i.e., more animals than the land could sustainably support).

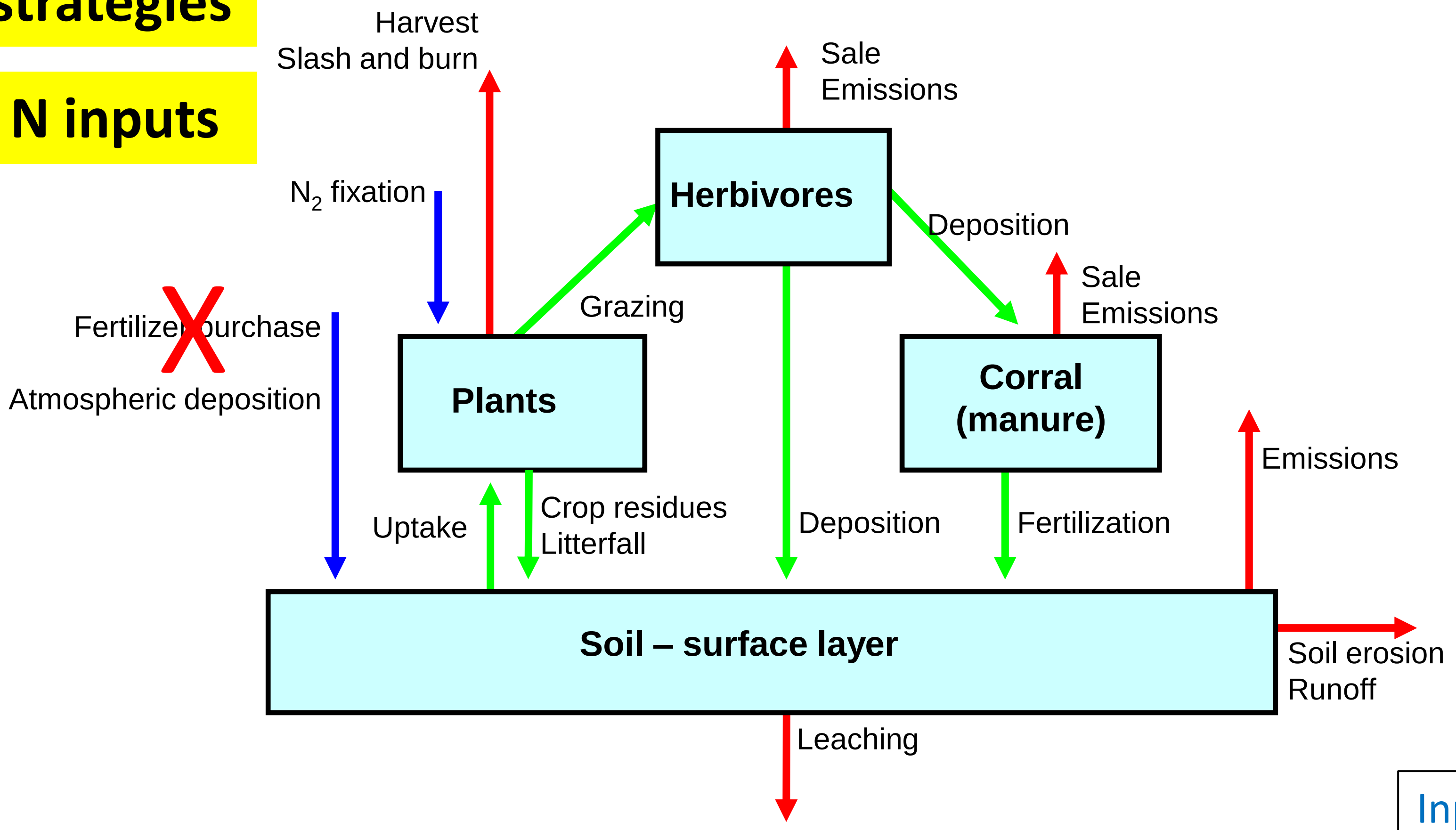
Guiding questions

- What are the relative roles roles of industrial N, biological N fixation, and organic N recycling in optimizing N use?

Nitrogen cycling in the Caatinga ecosystem

Management strategies

Few N inputs



Input fluxes: blue arrows
Output fluxes: red arrows
Internal cycling: green arrows

Adapted from Menezes et al. (2012)

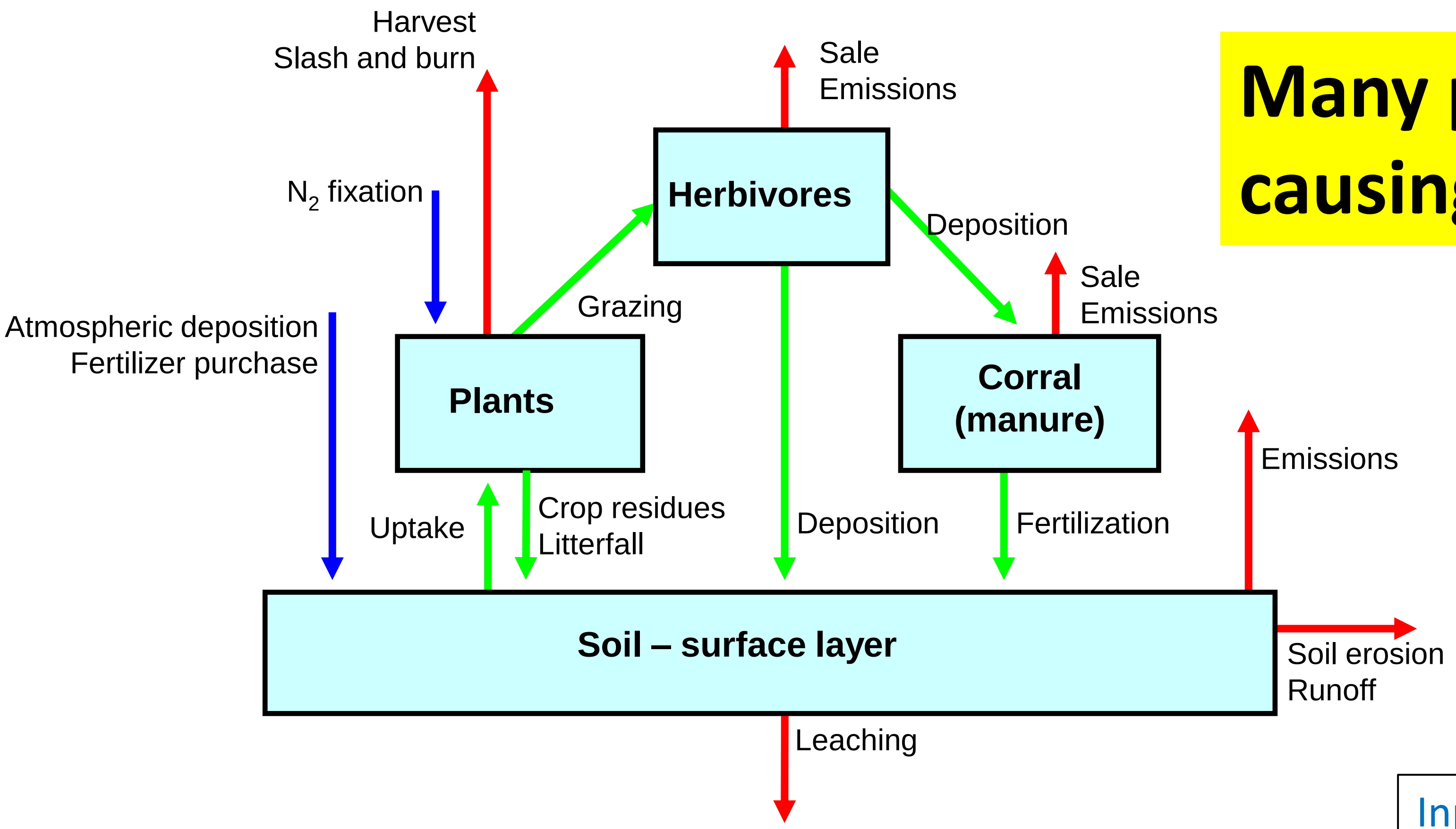
Atmospheric N deposition (2 studies published)

Deusdará, K.R.L., Forti, M.C., Borma, L.S. Menezes, R. S. C., Lima, J. R. S., Ometto, J. P. H. B. Rainwater chemistry and bulk atmospheric deposition in a tropical semiarid ecosystem: the Brazilian Caatinga. J Atmos Chem (2016). doi:10.1007/s10874-016-9341-9

MARIN, A. M. P., Menezes, R. S. C. Ciclagem de nutrientes via precipitação total, interna e escoamento pelo tronco em sistema agroflorestal com Gliricidia sepium. Revista Brasileira de Ciência do Solo, v.32, p.2573 - 2579, 2008.

About 2 to 5 kg ha^{-1} $year^{-1}$

Nitrogen cycling in the Caatinga ecosystem



Many processes causing N outputs

Input fluxes: blue arrows
Output fluxes: red arrows
Internal cycling: green arrows

Adapted from Menezes et al. (2012)

Main N losses from the system: How to mitigate it?

Slash and burn:

- N losses up to 500 kg ha^{-1} during burning of dense, mature native vegetation;
- It is necessary about 20 to 30 years of biological N fixation to recover it;
- What to do? No biomass should be burned.

Erosion:

- N losses due to soil erosion could be generally up to 30 to 40 kg ha^{-1} $year^{-1}$ in agricultural fields;
- Pastures could also present intermediate to high erosion rates;
- What to do? Soil erosion control measures must be implemented, otherwise N balance will be negative.

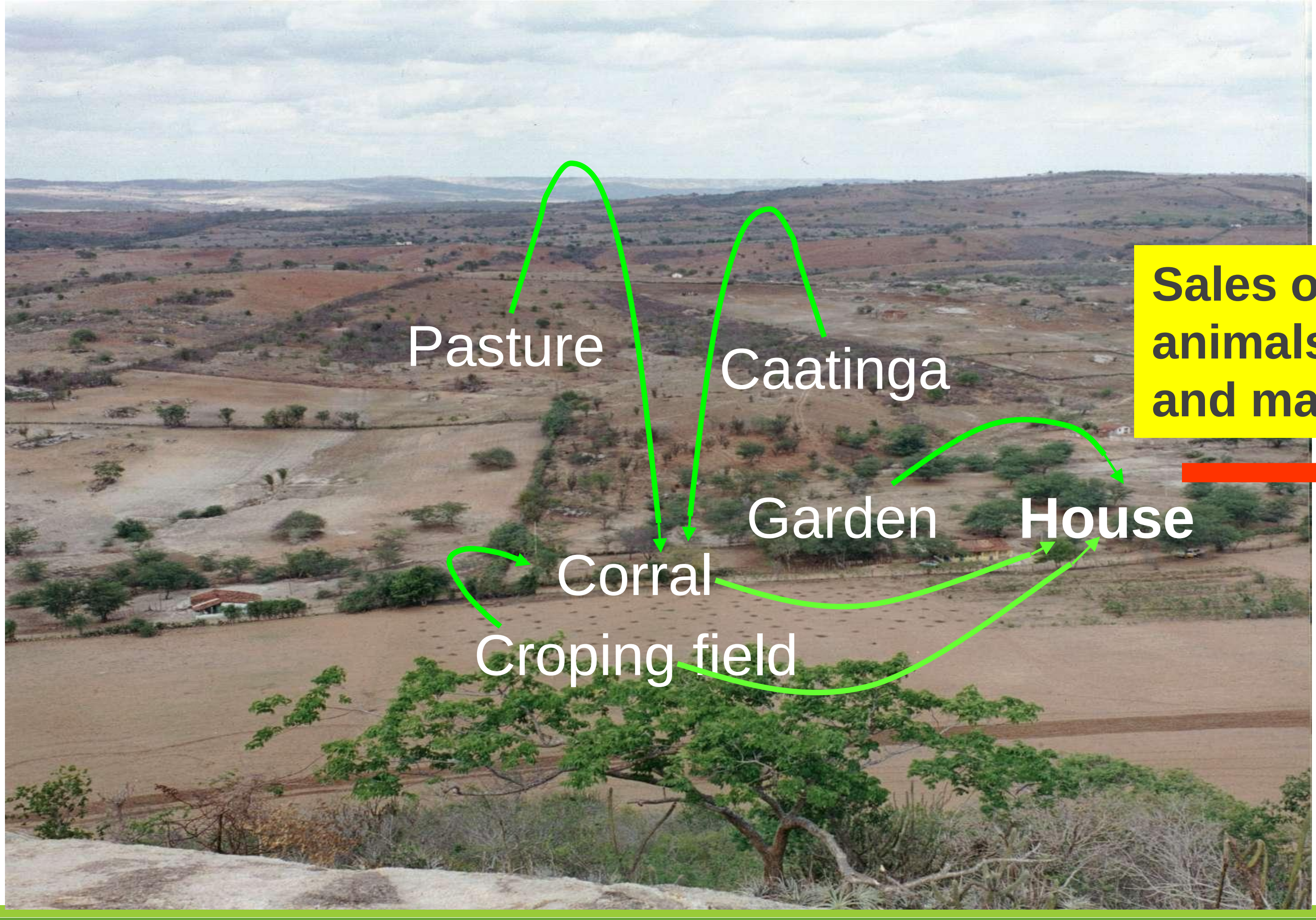
Emissions:

- N losses due to soil emissions are relatively low (~1 kg ha^{-1} $year^{-1}$) (Ribeiro et al., 2016);
- More studies are needed.

Guiding questions

- What are is the balance between fixation, immobilization and decomposition (losses) in the N cycle under different management and in different environments?

Quantification of nutrient fluxes and balances in six farms in NE Brazil during two years



Sales of animals, grains, milk and manure

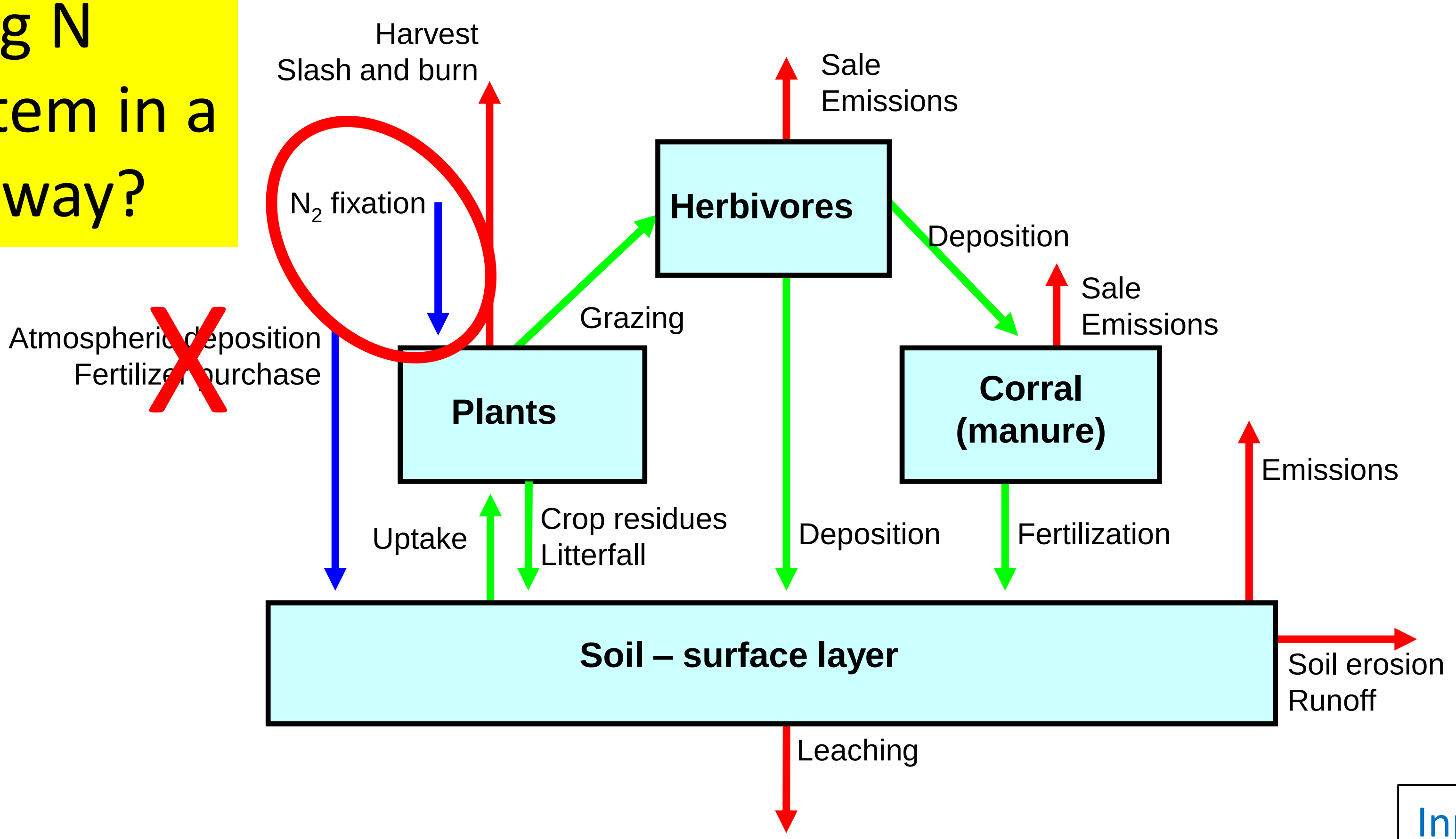
Average net nutrient balances in agricultural fields and pastures in six farms in the caatinga during two years (kg ha^{-1} $year^{-1}$)

Land use	Nitrogen	Phosphorus	Potassium
Agriculture	-16	- 1	-18
Pasture	- 3	- 0.1	- 4

- **Balances in native vegetation plots were positive for nitrogen and near zero for P and K.**
- **A great amount of the nutrients removed from agricultural fields and pastures end up in the corral**
- **Average manure sales (per farm): ~ 100, 40 e 150 kg $year^{-1}$ of N, P and K**

Nitrogen cycling in the Caatinga ecosystem

How to bring N into the system in a sustainable way?



Input fluxes: blue arrows
Output fluxes: red arrows
Internal cycling: green arrows

Adapted from Menezes et al. (2012)

Estimates of biological nitrogen fixation (BNF) in mature and regenerating caatinga areas

	MATURE VEGETATION		REGENERATING VEGETATION	
	Site 1	**Site 2**	**Site 1**	**Site 2**
Proportion of N fixers (%)	2,4	11,8	58	97
Mass of N fixers (kg)	170	625	1620	1310
Amount of N fixed (kg/ha)	3	11	26	21

MATURE CAATINGA
7 kg ha^{-1} $year^{-1}$

REGENERATING CAATINGA
23 kg ha^{-1} $year^{-1}$

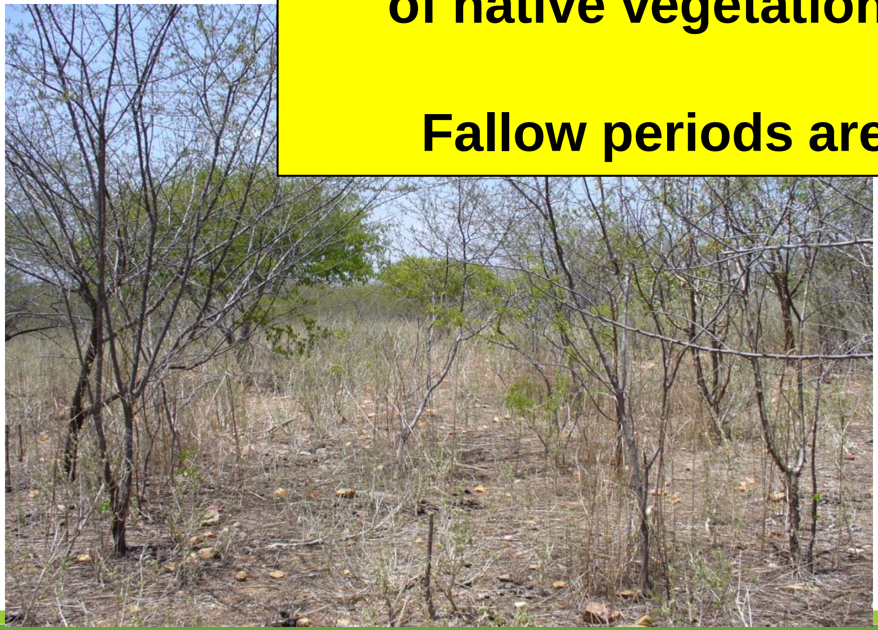
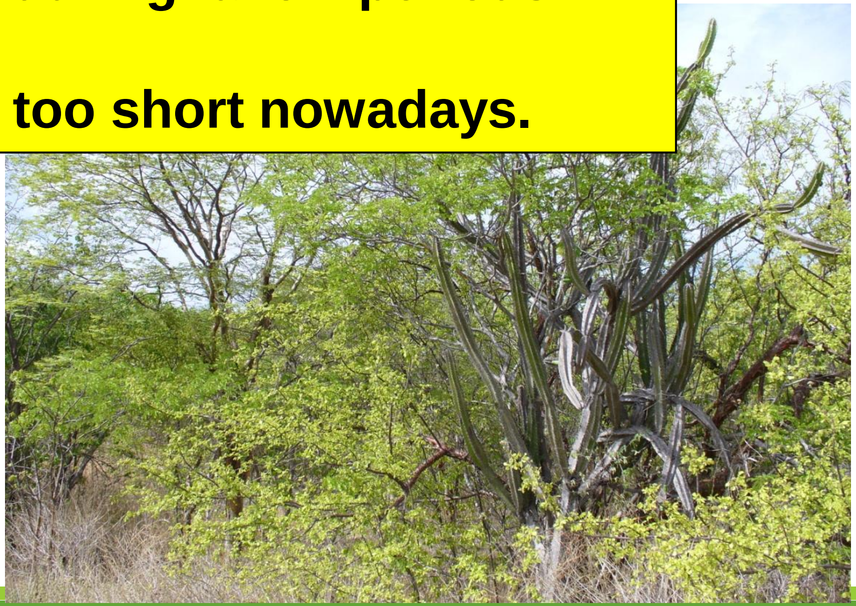
Guiding questions

- What are the limitations of biological N fixation under climate stress and under climate change?

Low water and P availability limit BNF. Climate change will make it worse.


Traditionally, soil fertility recovery was done through rotation of cropping areas and recovery of native vegetation during fallow periods.

Fallow periods are too short nowadays.

Litter N content in different successional stages of caatinga

Table 5 Average annual contents of nutrients in litter fractions in areas with caatinga vegetation regenerating for 1 (R1), 15 (R15), 37 (R37), and 57 years (R57) in Santa Teresinha, PB, Brazil

Areas	Leaves ($kg\ ha^{-1}$)	Twigs ($kg\ ha^{-1}$)	Miscellanea ($kg\ ha^{-1}$)	Total ($kg\ ha^{-1}$)
N				
R1	3.6 Ad[a]	0.07 Aa	4.88 Aa	8.6 d
R15	42.1 Aa	3.14 Ba	8.39 Ba	53.6 a
R37	31.3 Ab	1.63 Ba	8.11 Ba	41.0 b
R57	19.0 Ac	1.21 Ca	8.94 Ba	29.2 c

Greater ammounts in intermediate stages

Nutr Cycl Agroecosyst (2016) 105:25–38

Carbon and nutrient recovery along a succession gradiente of caatinga regeneration

Nutr Cycl Agroecosyst (2016) 105:25–38

Table 1 Average chemical and physical characteristics of soil samples (0–20 cm) from areas with caatinga vegetation regenerating for 1 (R1), 15 (R15) and 37 years (R37) and areas of mature caatinga regenerating for at least 57 years (R57), in Santa Teresinha, PB, Brazil

Areas	pH (water)	P (mg kg^{-1})	K^+ ($cmol_c$ kg^{-1})	Na^+ ($cmol_c$ kg^{-1})	Ca^{2+} ($cmol_c$ kg^{-1})	Mg^{2+} ($cmol_c$ kg^{-1})	C (g kg^{-1})	N (g kg^{-1})	Sand (g kg^{-1})	Silt (g kg^{-1})	Clay (g kg^{-1})
R1	5.86b[a]	2.72a	0.25b	0.12a	4.31a	1.37a	8.37c	0.70c	638a	93a	269a
R15	5.94b	1.55a	0.29ab	0.11a	5.02a	1.66a	8.61c	0.78c	645a	117a	239a
R37	5.79b	1.65a	0.31a	0.13a	3.91a	1.29a	14.10a	1.18a	668a	93a	239a
R57	6.41a	2.62a	0.29ab	0.11a	5.22a	1.36a	11.62b	1.06b	648a	123a	229a

[a] Averages followed by the same letter in the columns are not significantly different at the 0.05 level (Tukey test)

Up to 57 years of regeneration

Around 40% of increase in C and N levels
Increase of 1200 kg ha^{-1} in 57 years
Net increase of 21 kg N ha^{-1} $year^{-1}$

Just do the math:

N inputs due to BNF + atmospheric deposition ~ 25 to 30 kg ha^{-1}

Conversion of native forest to agriculture = losses of 3000 to 4000 kg N ha^{-1}

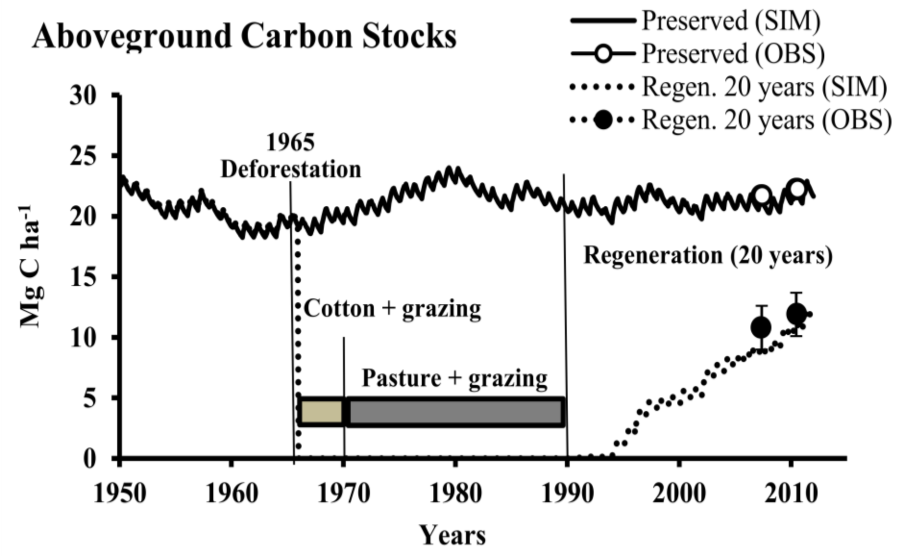
Time to recover original ecosystem N stocks = 100 to 150 years!

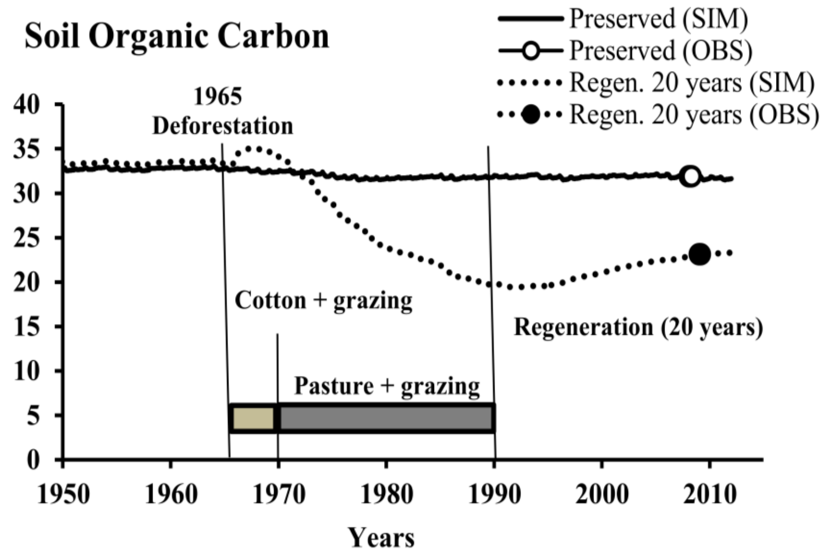
Actual falow periods = 10 to 15 years...

End result = soil fertility degradation, lower productivity, poverty, more degradation.

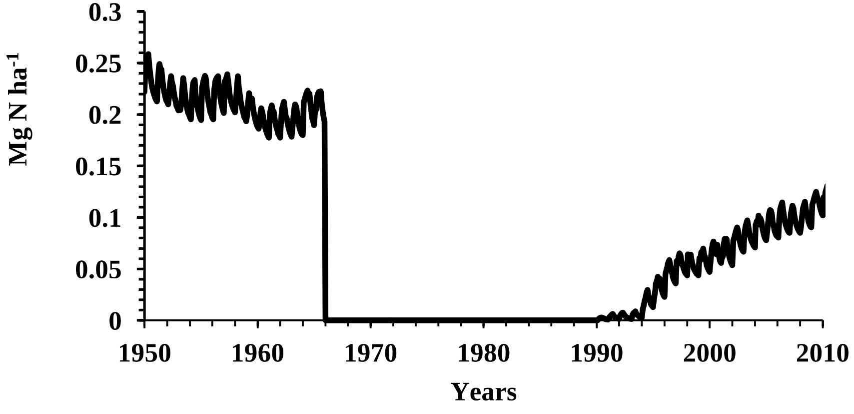
Carbon and nitrogen dynamics after land use change in the caatinga

Althof et al. (2016)

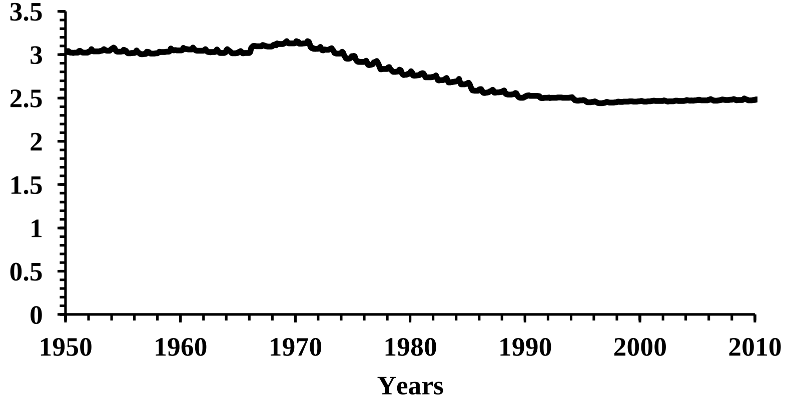




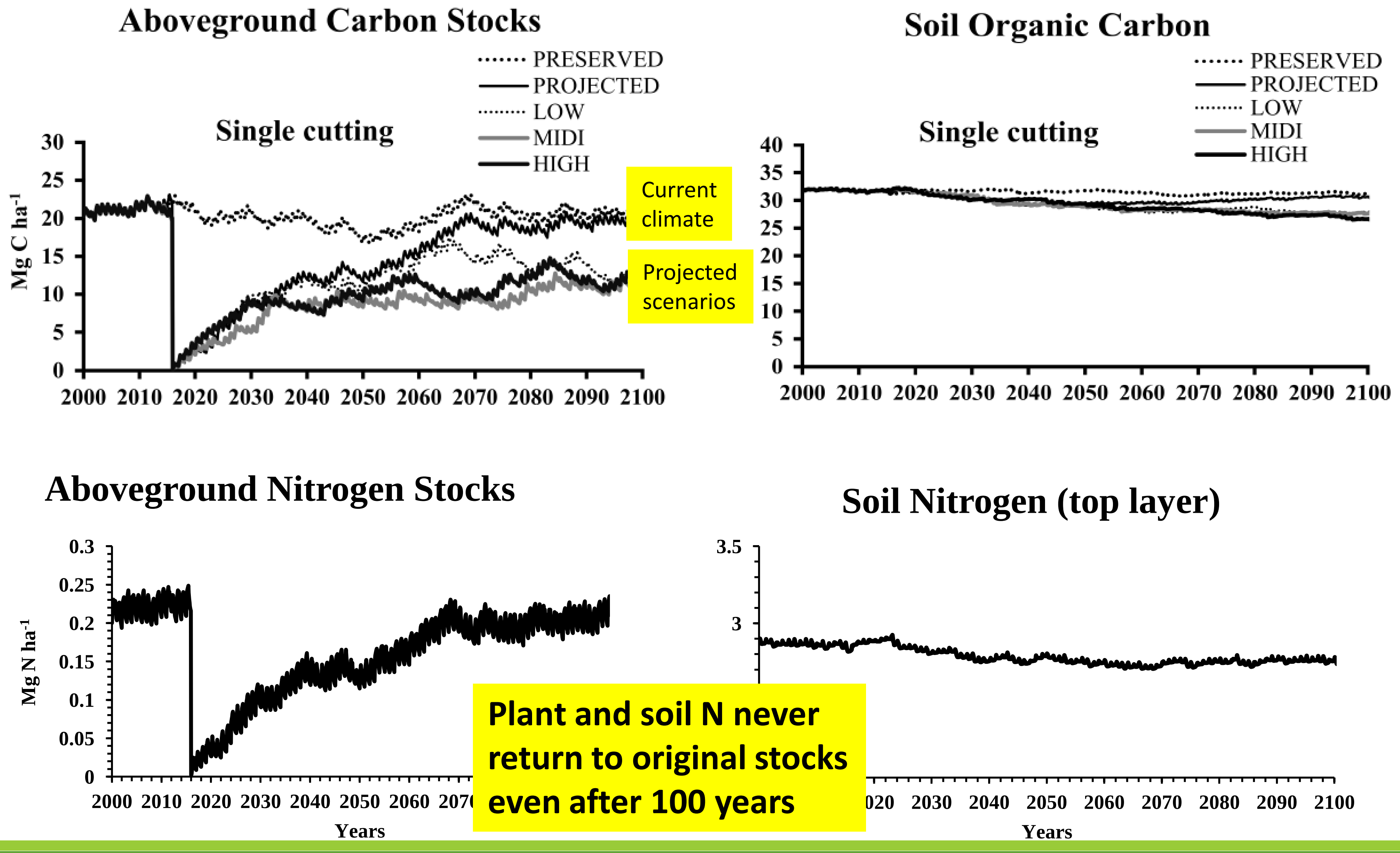
Aboveground Vegetation N Stock



Soil Nitrogen



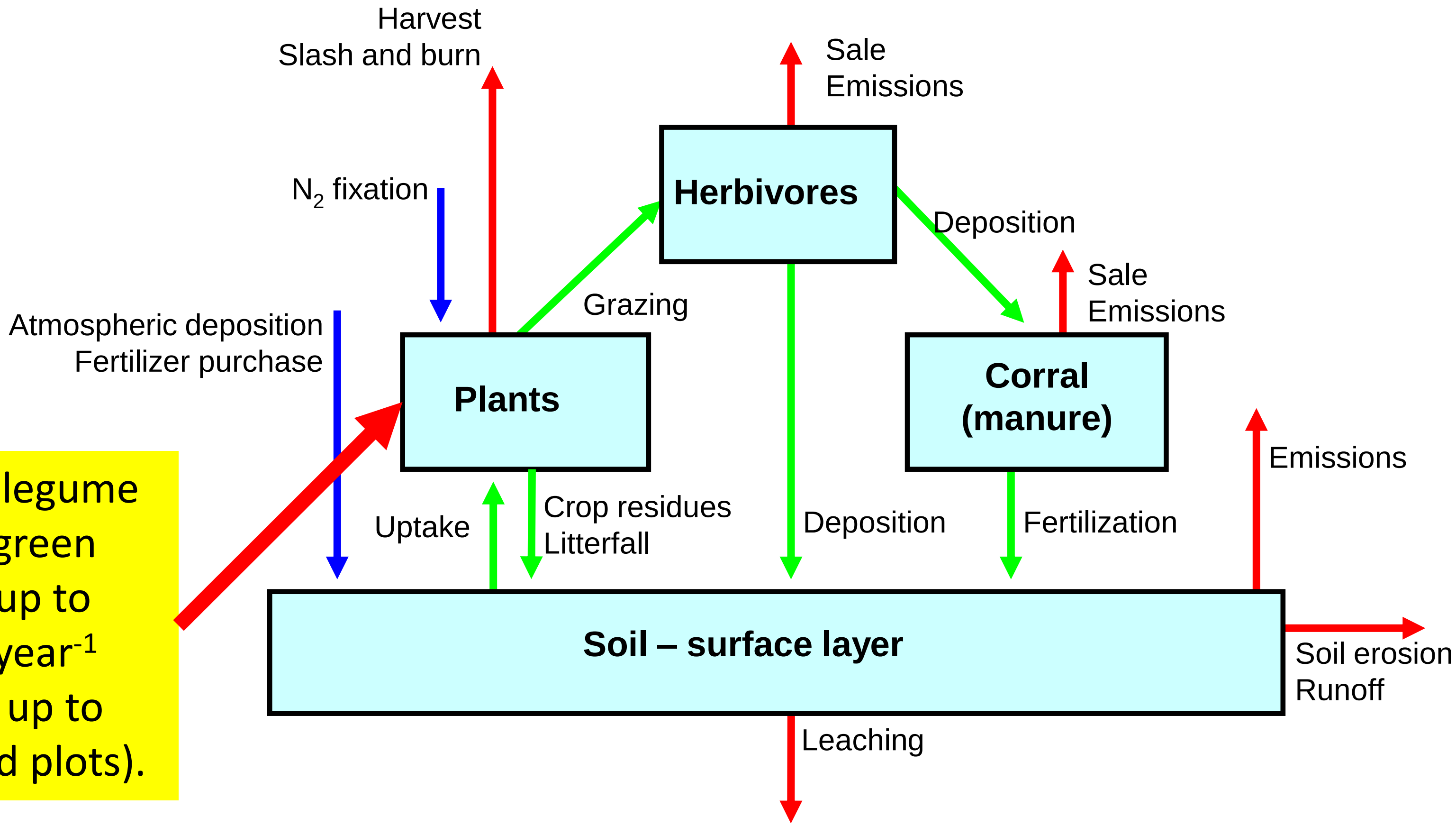
Regeneration of vegetation under current or projected climate changes



Guiding questions

- What innovative strategies for N management exist using plant breeding, microbial associations, fertilizer formulations and others?

Nitrogen cycling in the Caatinga ecosystem



Some crops and legume species used as green manure may fix up to 40 to 50 kg ha^{-1} year^{-1} of nitrogen (and up to 180kg in irrigated plots).

<u>TAKE HOME MESSAGES</u>:

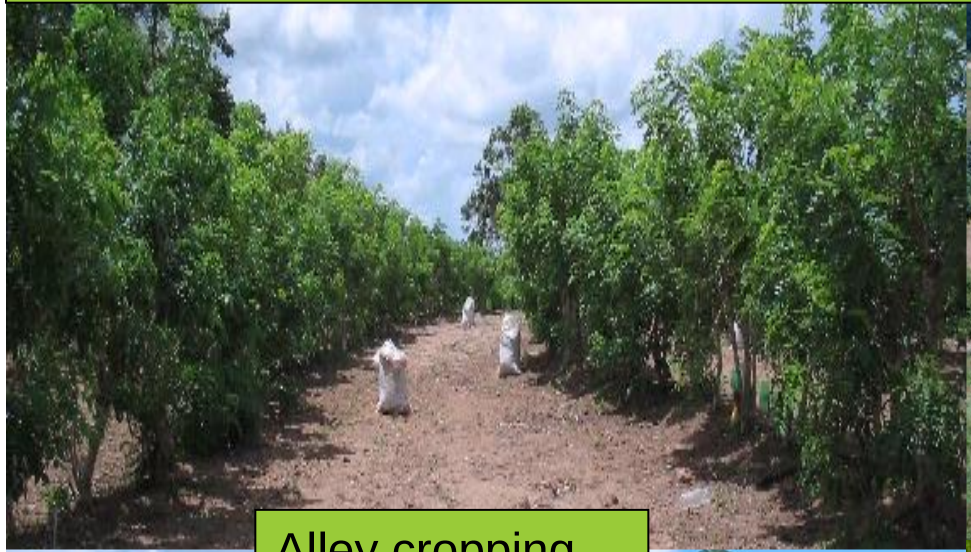
1) Atmospheric N fixation is the most feasible way to bring significant amounts of N into the system;

2) Very disturbed systems may require decades to over a century to recover natural fertility levels (if ever).

3) In some cases, therefore, external input of N may be necessary to recover the system.

Adapted from Menezes et al. (2012)

Agroforestry Systems

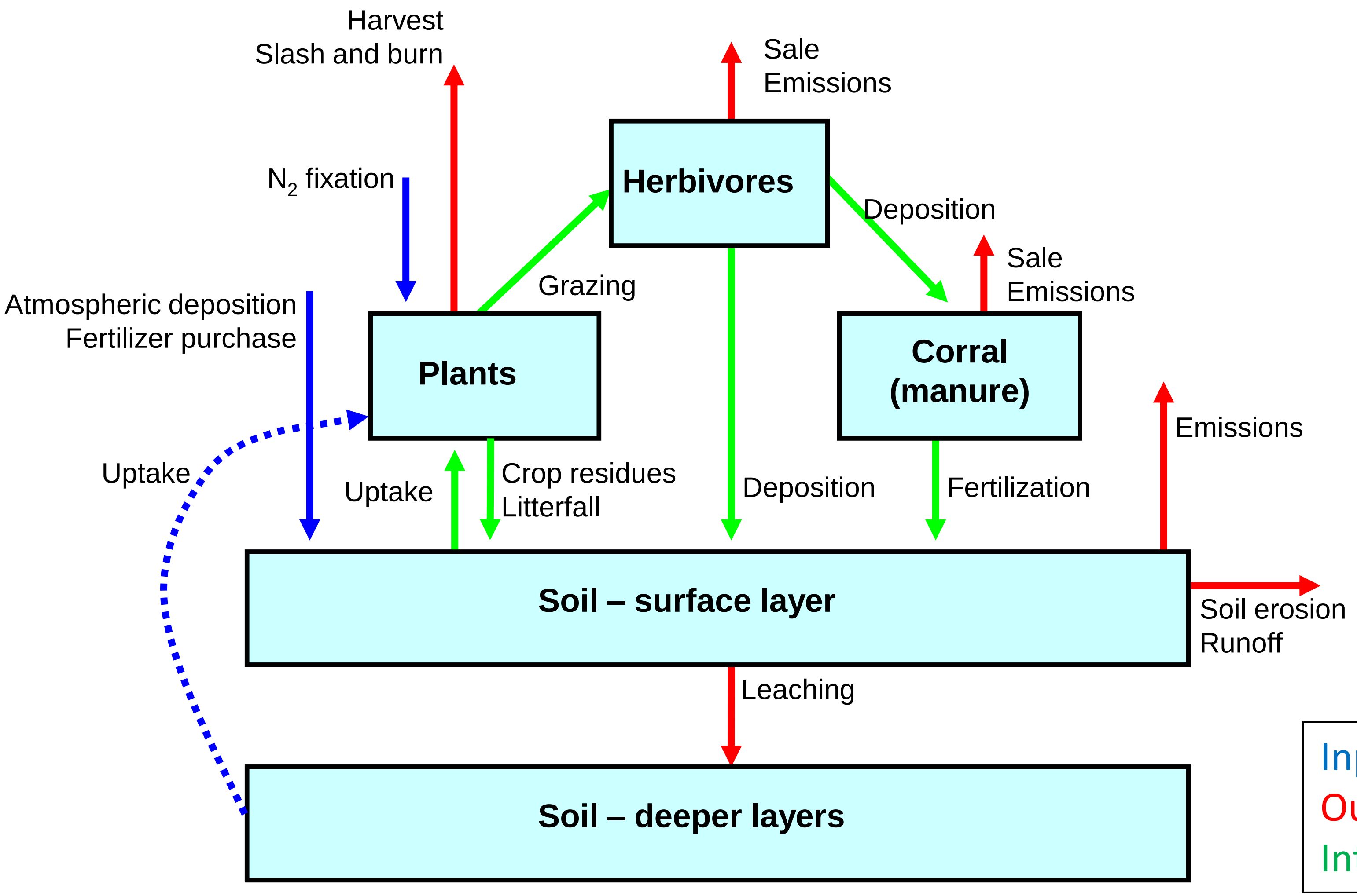


Mixed systems

Alley cropping

Silvopastoral systems

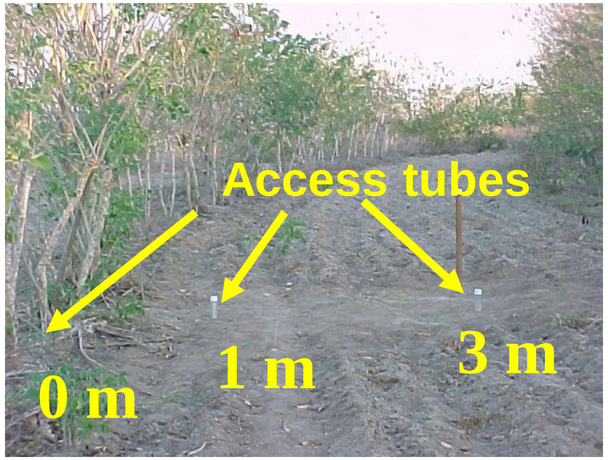
Nitrogen cycling in the Caatinga ecosystem

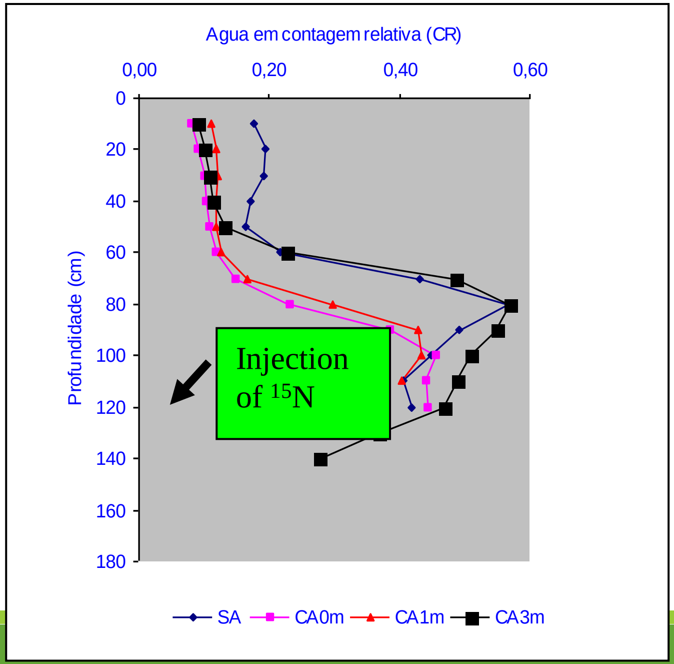


Input fluxes: blue arrows
Output fluxes: red arrows
Internal cycling: green arrows

Adapted from Menezes et al. (2012)

Trees may tap nutrients (and water) from deeper soil layers

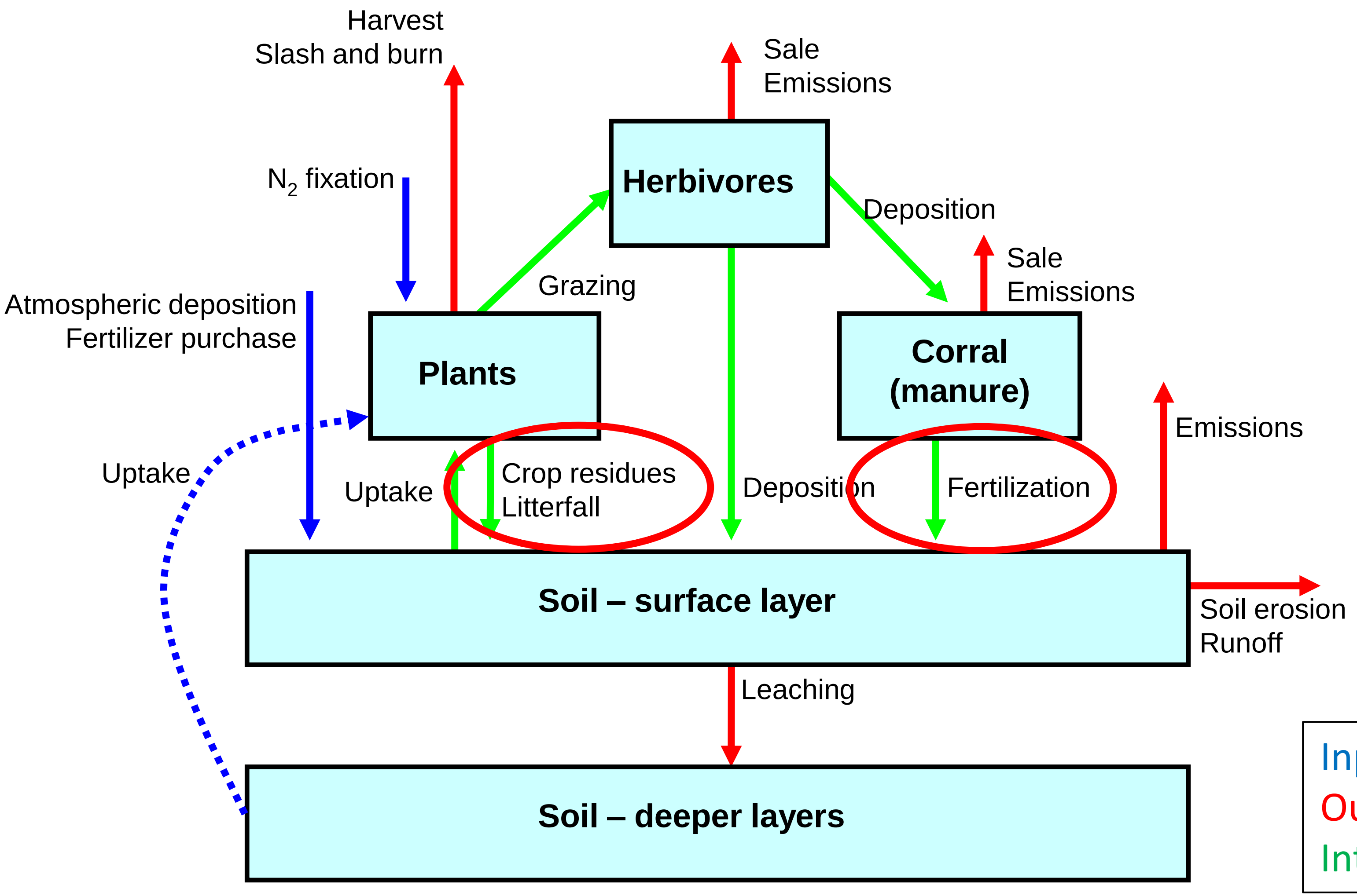




Gliricidia trees took up water and nitrogen from 120-150 cm of depth. Maize plants were not able to reach these resources.

Agroforestry systems: 150% more biomass production than maize plots without trees

Nitrogen cycling in the Caatinga ecosystem



Input fluxes: blue arrows
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Internal cycling: green arrows

Adapted from Menezes et al. (2012)

Organic fertilization

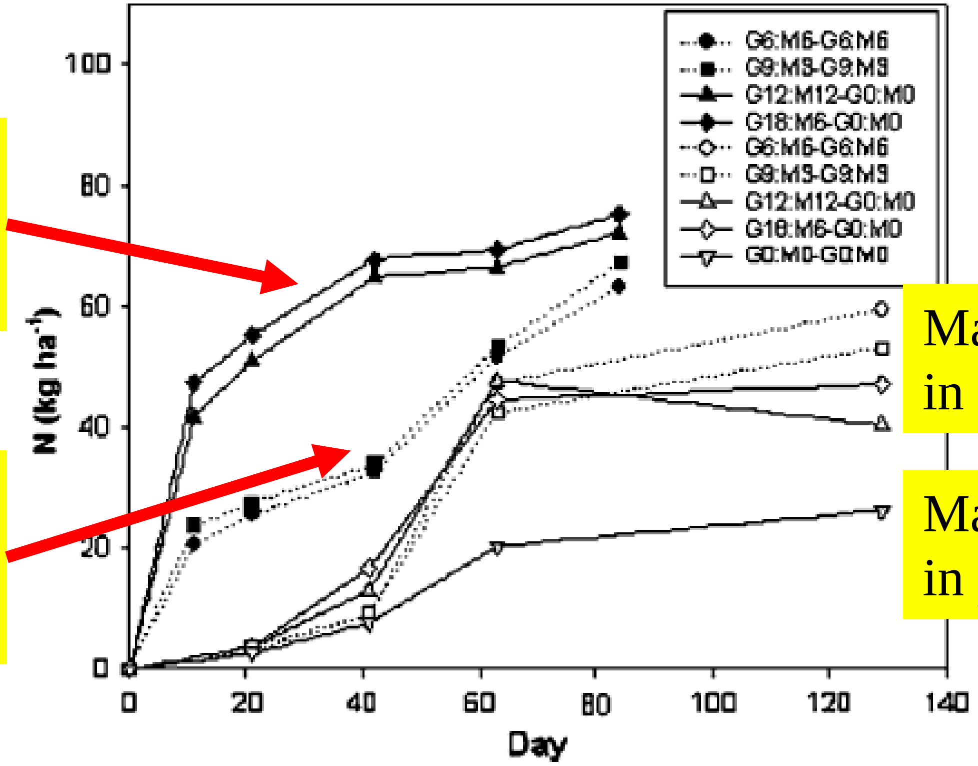
(Green and animal manures)

Up to 10 times more productivity with adequate practices of organic fertilization

Fertilization practices to sinchronize plant demand and soil N availability

N release:
100% of fertilizer at planting

N release:
Splitting fertilizer at planting and 40 DAP



Maize N accumulation in fertilized plants (~50 kg ha^{-1})

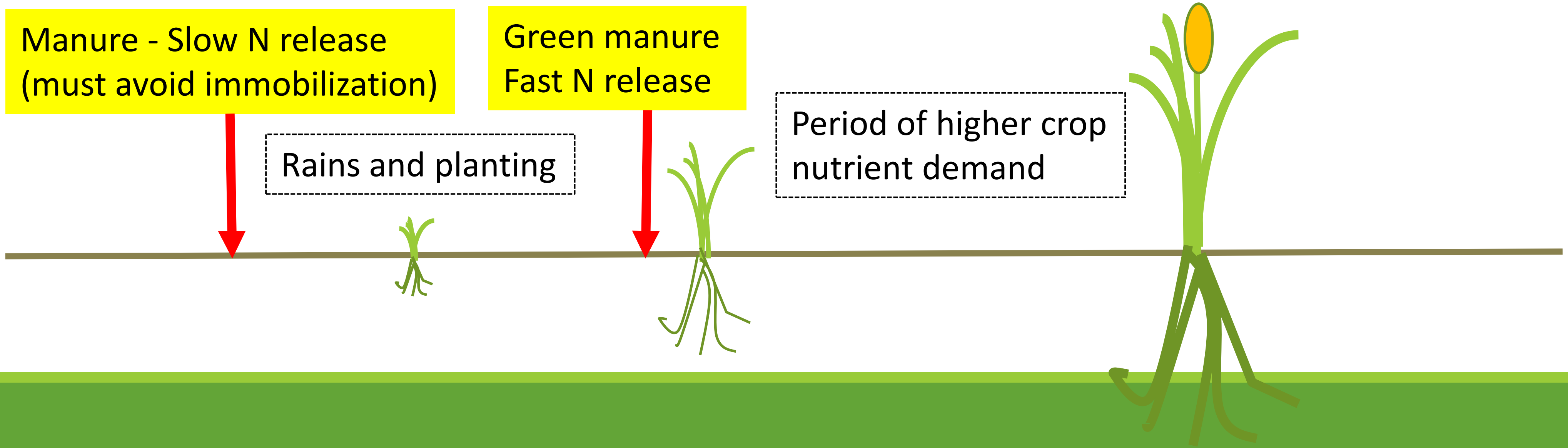
Maize N accumulation in plants without fertilization

Strategies for synchronization

Manure accumulates in the corral during the dry season;

Biomass from green manure species sprout during the rainy season and need time to accumulate biomass;

Based on this, manure should be incorporated before planting and green manure should be surface applied during the crop cycle, right before the period of higher nutrient demand. Composting, if possible, could also be done before the planting season and applied during planting.



Guiding questions

What is the role of public and private sector policy in improving N management?

Public policies and education to promote more adapted nutrient management practices.

Summary and conclusions

- N stocks in soils and vegetation are low, due to the low and variable precipitation;
- Nitrogen and phosphorus and are the most limiting soil nutrients in the caatinga;
- Use of fertilizers and irrigation not feasible in most of the Caatinga;
- BNF is the most sustainable way of adding N to the system;
- Control of processes that lead to N losses is crucial to maintain positive N balances;
- Need for more research on N emissions;
- Degraded systems may require over 100 years of BNF to recover natural N stocks;
- Agroforestry and use of organic fertilizers increase ecosystem productivity;
- Need for effective policies to promote sustainable nutrient management.

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