Rotating annual crops with perennial grassland may increase micronutrient content of foods from integrated crop-livestock systems

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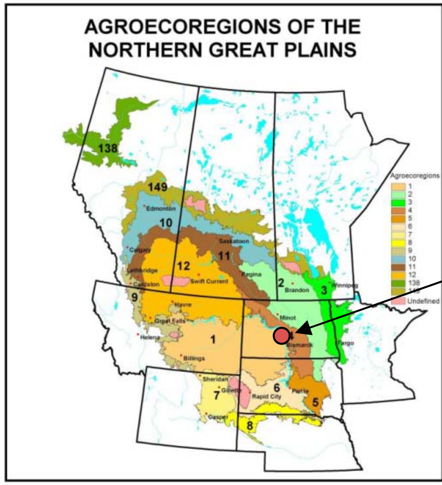
- **Geography**
  - Northern Great Plains (NGP)
- **Climate**
  - Semiarid/Sub-humid with evaporation > precipitation
  - MAP: ≈410 mm, MAT: ≈5°C
  - Growing season: ≈135 d
- **Soils**
  - Glaciated Mollisols with loess cap
- **Native vegetation (relatively recent)**
  - Mixed-grass prairie



Padbury et al. (2002)

NGPRL

Current state of agriculture on Northern Great Plains

Generally, dis-functional agroecosystems now

Native prairie, perennial grassland and annual crops on the Northern Great Plains

- Very little pure native prairie remains on NGP
  - Converted to annual cropland
  - Remaining native prairie has been invaded by European grass and forb species
  - Some annual cropland has been reseeded to perennial grassland but usually with cheaper seed of tame grass and forb species

Native prairie in NGP region

Introduced perennial plants for hay or grazing in NGP region

Why has perennial vegetation been replaced with annual crops on the NGP?

- Complicated story!
  - Best left for a separate presentation

Native and domestic grassland animals we eat

Wild native animals	Domestic animal equivalents
Bison	Cattle
Elk (wapiti)	Cattle
Bighorn sheep	Sheep
Deer	Sheep and goats
Antelope	Sheep and goats
Geese	Geese
Ducks	Ducks
Grouse and turkeys	Chickens and turkeys
Rabbits	Rabbits

Agroecologically sustainable?

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Bigger challenge - current rural farming culture

- Children often do not return to farming family farm too isolated from
  - other people, basic services and cultural amenities (e.g. live music, theater, restaurants, sports, etc.)
- And/or farming family is struggling to survive financially
  - adult children discouraged from returning
- Vicious circle!
- Unique food production, which many consumers value more now, often lacking

Rotating annual crops with perennial forages

Critical Need to Increase Human Intake of Several Minerals (e.g. Fe, Mg, Zn)

- Nutrient stripping: the global disparity between food security and soil nutrient stocks. Davey Jones et al., Journal of Applied Ecology, 2013,

- Plant breeding to control zinc deficiency in India: how cost-effective is biofortification? Alexander Stein et al., Public Health Nutrition, 2007, 10, 492-501.

- Soil fertility and hunger in Africa. Pedro Sanchez, Science, 2002, 295, 2019-2020.

Critical Need to Increase Human Intake of Several Minerals (e.g. Fe, Mg, Zn)

"Micronutrients are defined as substances in foods that are essential for human health and are required in small amounts. They include all of the known vitamins and essential trace minerals. Micronutrient malnutrition affects ⅓ to ½ of the global population. It causes untold human suffering and levies huge costs on society in terms of unrealized human potential and lost economic productivity."

From Dennis Miller and Ross Welch 2013, Food system strategies for preventing micronutrient malnutrition. Food Policy, 42, 115-128.

Critical Need to Increase Human Intake of Several Minerals (e.g. Fe, Mg, Zn)

- Optimal micronutrients delay mitochondrial decay and age-associated diseases. Bruce Ames, Mechanisms of Ageing and Development, 2010, 131, 473-479.

- Low micronutrient intake may accelerate the degenerative diseases of aging through allocation of scarce micronutrients by triage. Bruce Ames, Proc. Nat. Acad. Sci., 2006, 103, 17589-17594.

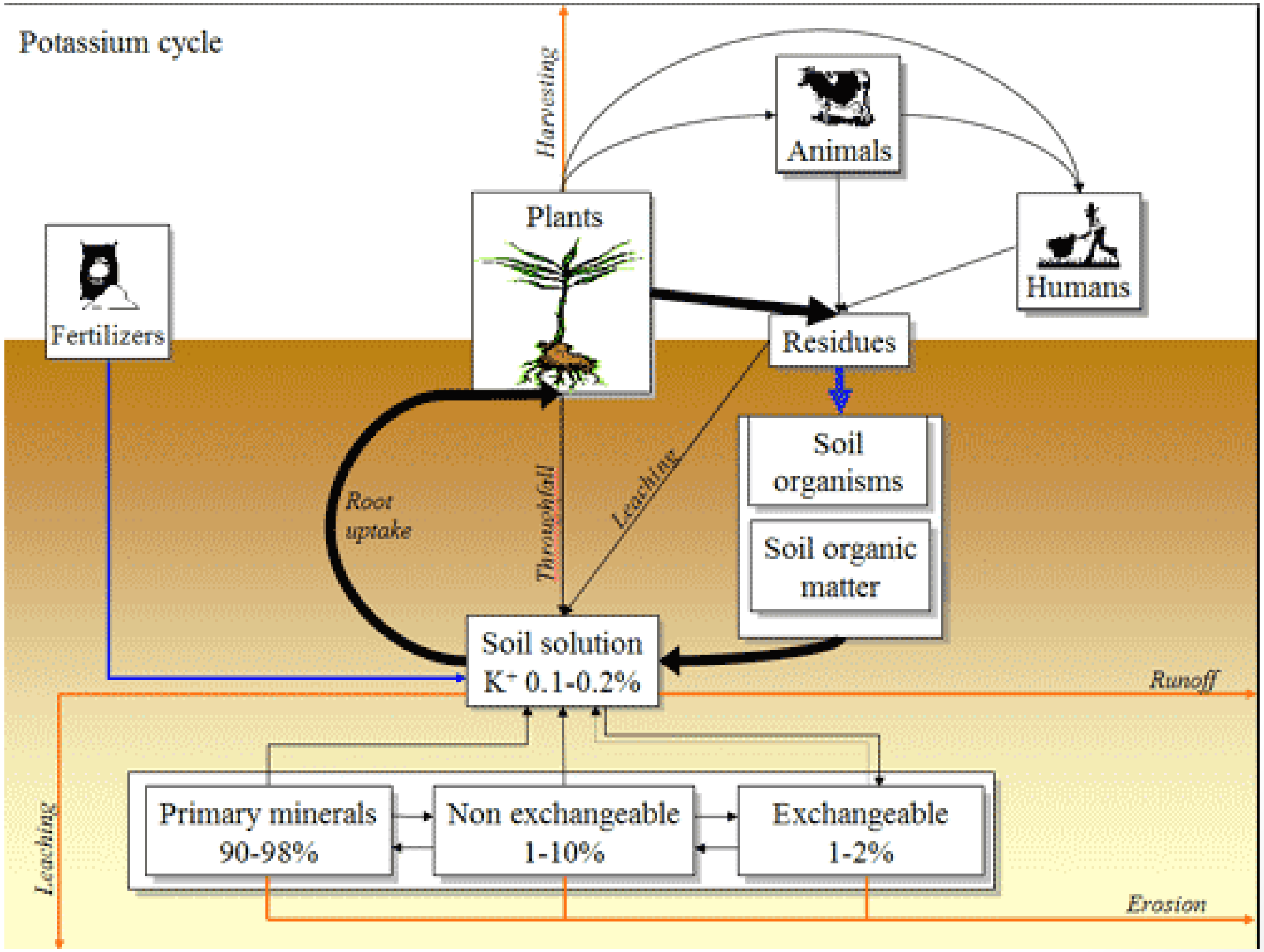
- DNA damage from micronutrient deficiencies is likely to be a major cause of cancer. Bruce Ames, Mutation Research, 2001, 475, 7-20.

Critical Need to Increase Human Intake of Several Minerals (e.g. Fe, Mg, Zn)

"Inadequate dietary intakes of vitamins and minerals are widespread, most likely due to excessive consumption of energy-rich, micronutrient-poor, refined food. Inadequate intakes may result in chronic metabolic disruption, including mitochondrial decay. Deficiencies in many micronutrients cause DNA damage, such as chromosome breaks, in cultured human cells or *in vivo*. Some of these deficiencies also cause mitochondrial decay with oxidant leakage and cellular aging and are associated with late onset diseases such as cancer, (neural decay also)"

from Bruce Ames, PNAS 2006, 103,17589-17594. Emeritus professor University of California- Berkeley & Senior Scientist, Children's Hospital Oakland Research Institute (87 years old)

Recycle more minerals back to cropland but carefully!



Make better use of inefficient animal nutrient use

Only a small proportion of the amount of a nutrient element consumed by an animal is used for maintenance, growth, milk or fiber production with the remainder excreted.

Minerals in cattle excreta and nutrient concentration in plant DM

Element	% in feces	% in urine
N	20 - 55	45 - 80
P	95+	< 5
S	10 - 94	6 - 90
K	10 - 30	70 - 90
Na	about 40	about 60
Ca	96 - 99	1 - 4
Mg	70 - 90	10 - 30
Cl	about 45	about 55
Fe	95+	< 5
Mn	95+	< 5
Zn	95+	< 5
Cu	95+	< 5
Co	< 50	> 50
I	40 - 45	55 - 60
B	30 - 50	50 - 70
Mo	30 - 70	30 - 70
Se	60 - 80	20 - 40

Cattle daily excretions

- *8 – 12 urinations*
- *11 – 34 liters urine*
- *0.16 – 0.5 m^2 of soil surface covered per urination*
- *0.15 – 0.76 m^3 of soil affected per urination*

- *11 – 16 defecations*
- *2.7 – 5.9 kg DM defecated*
- *0.05 – 0.09 m^2 of soil surface covered per defecation*
- *0.08 – 0.16 m^3 of soil affected per defecation*

Indirect benefits of manure and organic matter additions for enhanced mineral uptake

- Change chemical, physical and biological characteristics of soil
  - Improve physical soil structure and water holding capacity
  - Then more extensive root development possible and
  - More soil microorganism activity

Study 1 Design

- Study initiated in 1994 using cropland that had been seeded to perennials lucerne and wheatgrass in 1989/1991
- Half of plots were hayed in 1994 and half had perennial forage left to decay (whole plot treatment)
- Type of tillage (conventional tillage, minimum tillage and no tillage treatments began in 1995 (split plot treatment)
- Nitrogen fertilization rate applied in spring (split-split plot trt)
- Dry peas (2000 crop) and spring wheat (2001 crop) samples analyzed for Ca, Cu, Fe, K, Mg, Mn, P and Zn using inductively coupled argon plasma emission spectrometry after digestion with acid
- Selenium concentrations determined with atomic absorption spectrometry after digestion with acid

Study 1 Results

- No difference ($P > 0.05$) in dry pea production in 2000, but wheat production in 2001 was 2.8% greater ($P < 0.01$) where perennial grass was left to decay in 1994.
- Copper and iron concentrations were 19 and 7%, respectively, greater ($P \leq 0.05$) in dry pea when perennial grass was left to decay on the crop field.
- Copper and iron concentrations were 296 and 138%, respectively, greater ($P \leq 0.05$) in wheat when perennial grass was left to decay on the crop field.
- Magnesium concentration in spring wheat was 3% higher ($P \leq 0.05$) when perennial grass was removed.

Study 2 Design

Study began on good, well-drained silt-loam soil growing perennial forages.

Annual Cropping Sequence

1999-2006

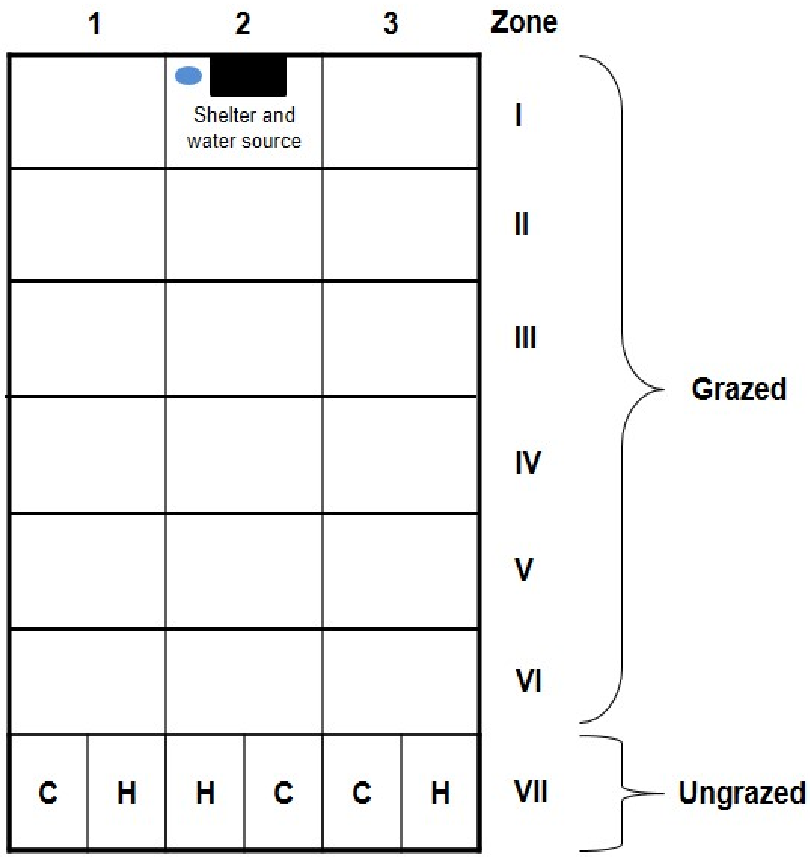
1. Oat / Pea
2. Triticale / Sweet Clover
3. Corn

2007-2011

1. Oat / Alfalfa / Hairy Vetch / Red Clover
2. Brown Midrib Sorghum-Sudangrass / Sweet Clover / Red Clover
3. Corn

Residue Management Treatments

- GRAZED: Residue removed by grazing.
- CONTROL, C: No residue removal.
- HAYED, H: Residue removed with a baler.



Study 2 Results

- No difference ($P \geq 0.28$) in maize grain production in 2007 and 2011 across grazed and non-grazed/hayed areas.
- Maize calcium concentration was higher ($P = 0.01$) in the non-grazed/hayed area and decreased linearly across the fields to the part of the fields closest to water, shelter and supplement.
- Copper, iron, magnesium, manganese, selenium and zinc concentrations were not affected ($P \geq 0.28$) by which part of the field the maize grew in, but potassium was lower ($P < 0.01$) in non-grazed/hayed area in 2011.

Conclusions

- Concentrations of some minerals may be increased in maize, dry peas and wheat by rotating perennial forages with annual crops and recycling vegetation and livestock excreta on cropland.

- Beyond the potential value of recycling livestock forages and excreta back to crop fields, animal-source foods are good sources of micronutrients such as iron, zinc and several vitamins plus ‘meat factors’ enhance bioavailability of micronutrients in diets containing seeds with anti-nutrients (e.g. polyphenols and phytic acid).

Conclusions

- If mineral supplements are fed to livestock, then it's probably better to carefully recycle them back to fields via livestock rather than enrich pen soils with minerals by feeding stock in pens and later hauling only part of their excreta (manure) to fields.

- Need for new methods for improved recycling of minerals in feces and urine from confined livestock back to fields (e.g. precision harvesting in pens and precision application on fields, trained livestock and urine collection areas in pens?).

Final Thoughts

Much more ecologically-sustainable integrated crop-livestock production will probably not occur unless educated urban consumers want and support it.

It will require expensive changes in agriculture and food sectors.

Final Thoughts