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Poop For You: A Case Study of the Manure Matching Problem

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Outline

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1. Project Overview
2. Methodology
   a. Assumptions
   b. Nomenclature
   c. Formulation
3. Case Study
4. Results
5. Conclusions

Motivation

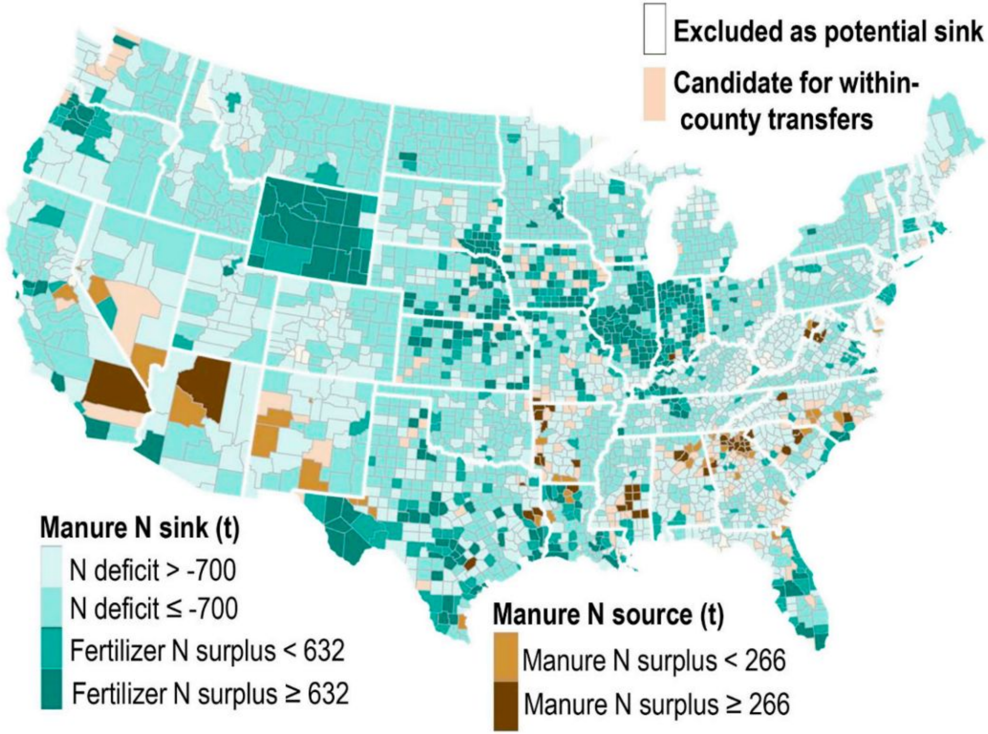

Figure source: [3]

N in manure produced

≈

Synthetic N fertilizer purchased

[1]

Research Question

How can manure be optimally re-allocated to minimize total costs?

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Assumptions

1. Losses are negligible
2. A central entity controls the manure market
3. Individual farms can be aggregated to the county level

What is a Mixed Integer Program (MIP)?

$$\left.\min c^T x + d^T y\right\}\text{objective function}$$

s.t.

$$\left.\begin{array}{l} Ax + By \leq q \\ \left.\begin{array}{l} x \in \mathbb{R}^n \\ y \in \mathbb{Z}^m \end{array}\right\}\text{decision variables} \end{array}\right\}\text{constraints}$$

Formulation: Variables

Sets

I^+ : counties with excess manure (sources)

I^- : counties in need of manure (sinks)

K : manure treatments

Decision Variables

x_{ijk} : amount of type k manure transported from county i to county j

y_{ijk} : whether manure type k is transported from county i to county j

w_{ik} : whether source county treats manure to type k or sink county receives type k manure

z_i : amount of manure disposed of in source county or synthetic fertilizer purchased in sink county

q_i : whether manure is disposed of in source county or synthetic fertilizer is purchased in sink county

Formulation: Objective Function

$$\min \sum_{i\in I^+}\sum_{j\in I^-}\sum_{k\in K}\left(c^v_{ijk}x_{ijk}+c^f_{ijk}y_{ijk}\right) \quad \Bigg\} \text{ transportation costs}$$

$$+\sum_{j\in I^-}\sum_{k\in K}\left(p^v_{jk}\sum_{i\in I^+}x_{ijk}\right) \quad +\sum_{i\in I^+}\sum_{k\in K}\left(p^v_{ik}\sum_{j\in I^-}x_{ijk}\right) \quad \Bigg\} \text{ manure application costs}$$

$$+\sum_{i\in\{I^+,I^-\}}\sum_{k\in K}p^f_{ik}w_{ik} \quad +\sum_{i\in\{I^+,I^-\}}\left(t^v_i z_i+t^f_i q_i\right) \quad \Bigg\} \text{ manure disposal \& synthetic fertilizer costs}$$

Formulation: Constraints

$\sum_{j \in I^-} \sum_{k \in K} x_{ijk} + z_i = s_i$	$\forall\, i \in I^+$	1: source mass balance
$\sum_{i \in I^+} \sum_{k \in K} x_{ijk} + z_j = d_j$	$\forall\, j \in I^-$	2: sink mass balance
$\sum_{j \in I^-} x_{ijk} \le s_i w_{ik}$	$\forall\, i \in I^+, k \in K$	3: supply binary variable
$\sum_{i \in I^+} x_{ijk} \le d_j w_{jk}$	$\forall\, j \in I^-, k \in K$	4: demand binary variable
$x_{ijk} \le \min\{s_i, d_j\} y_{ijk}$	$\forall\, i \in I^+, j \in I^-, k \in K$	5: transport binary variable
$z_i \le s_i q_i$	$\forall\, i \in I^+$	6: excess supply binary variable
$z_j \le d_j q_j$	$\forall\, j \in I^-$	7: unmet demand binary variable

Formulation: Decision Variable Bounds

$0 \leq x_{ijk} \leq \min\{s_i, d_j\}$	$\forall\, i \in I^+, j \in I^-, k \in K$
$y_{ijk} \in \{0,1\}$	$\forall\, i \in I^+, j \in I^-, k \in K$
$w_{ik} \in \{0,1\}$	$\forall i \in I, k \in K$
$0 \leq z_i \leq s_i$	$\forall i \in I^+$
$0 \leq z_j \leq d_j$	$\forall j \in I^-$
$q_i \in \{0,1\}$	$\forall i \in I$

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Case Study: CA-CO-NV-UT-AZ-NM

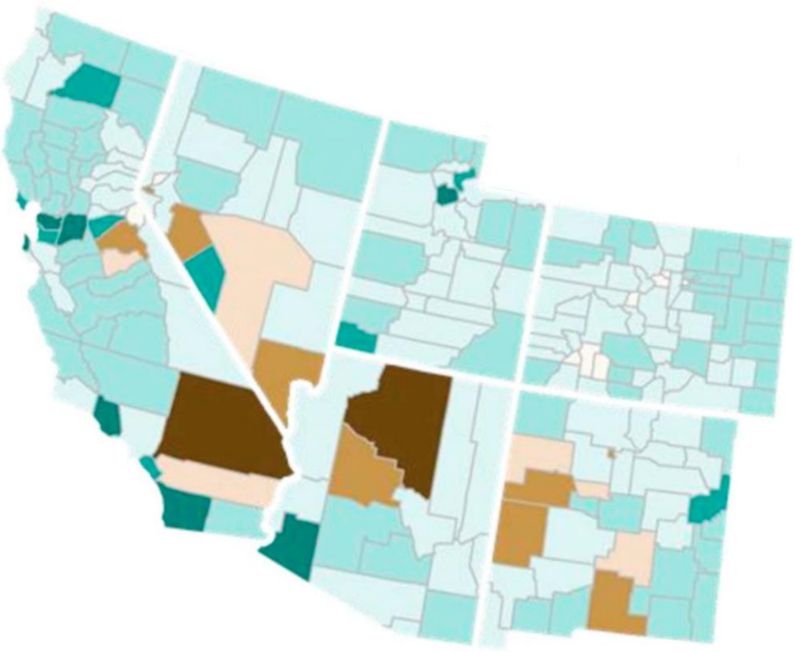
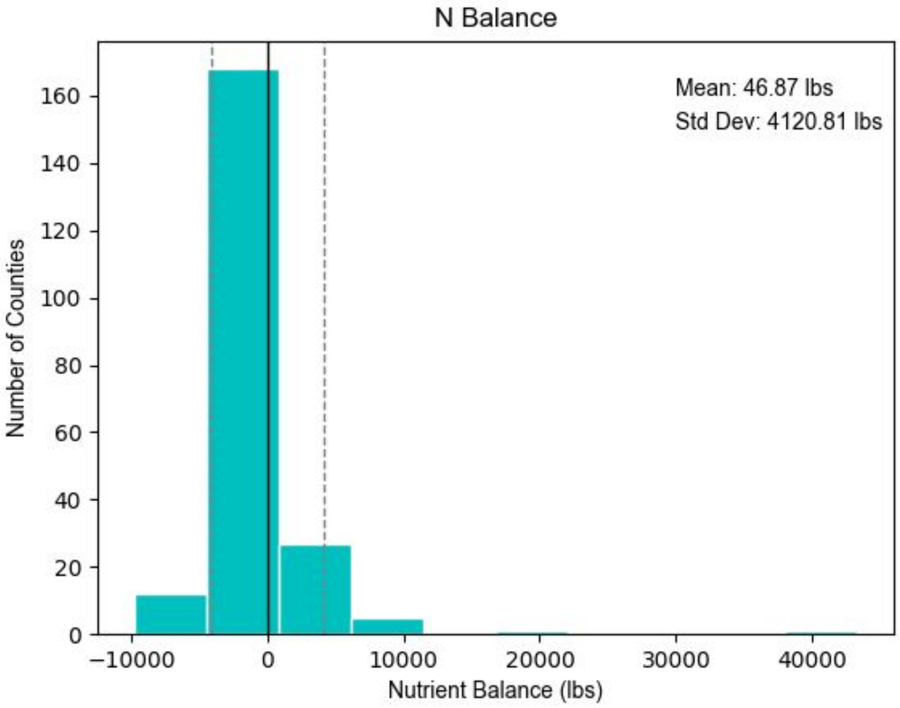


Figure source: [3]

Case Study: Nitrogen Balance



Parameters

Symbol	Description	Value	Units	Source
s_i	Supply of manure from each source county	-	tons	[2]
d_j	Demand of manure for each sink county	-	tons	[2]
c_{ij}^V	Distance between counties (straight-line distance)	-	miles	[9]
	Cost of manure transport	$0.0089	$ / mi - lb N	[4]
p_j^v	Variable cost of applying manure (price of manure)	$0.63	/lb N	[5]
t_i^f	Fixed cost of manure disposal	$141,894	-	[6]
t_i^v	Variable cost of manure disposal	$0.53	/lb N	[7]
t_j^v	Variable cost of synthetic fertilizer	$0.92	/lb N	[8]

All other parameters assumed to be zero

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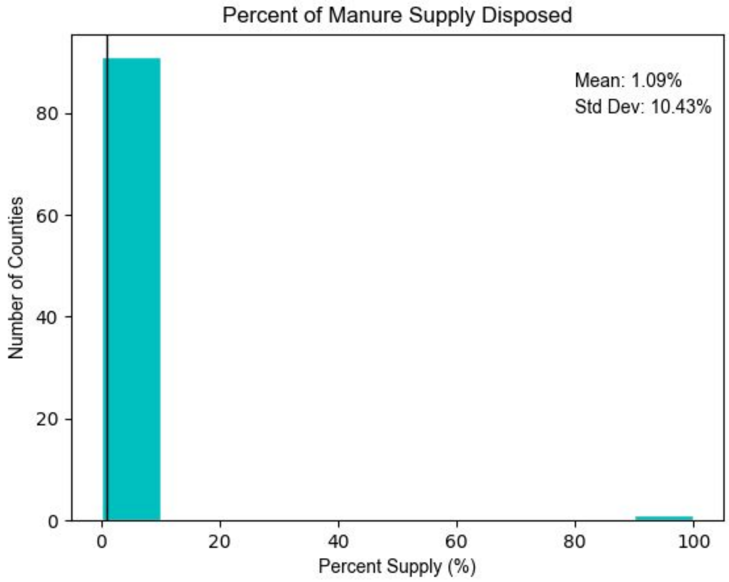
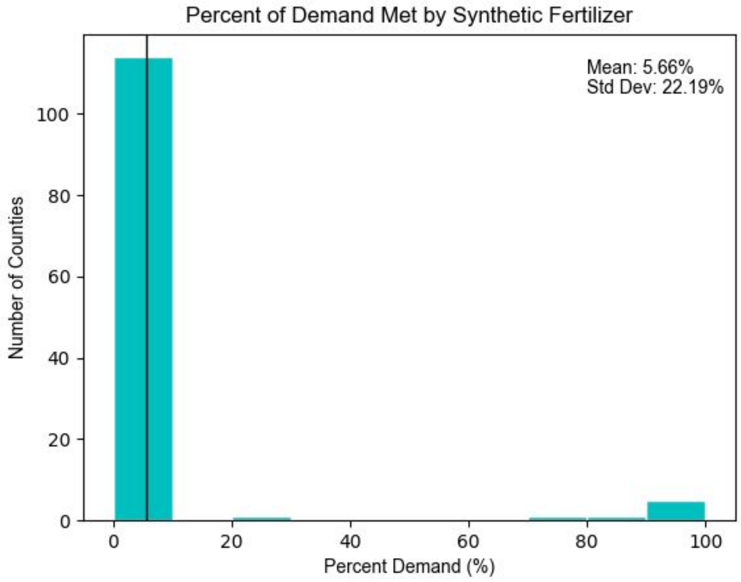
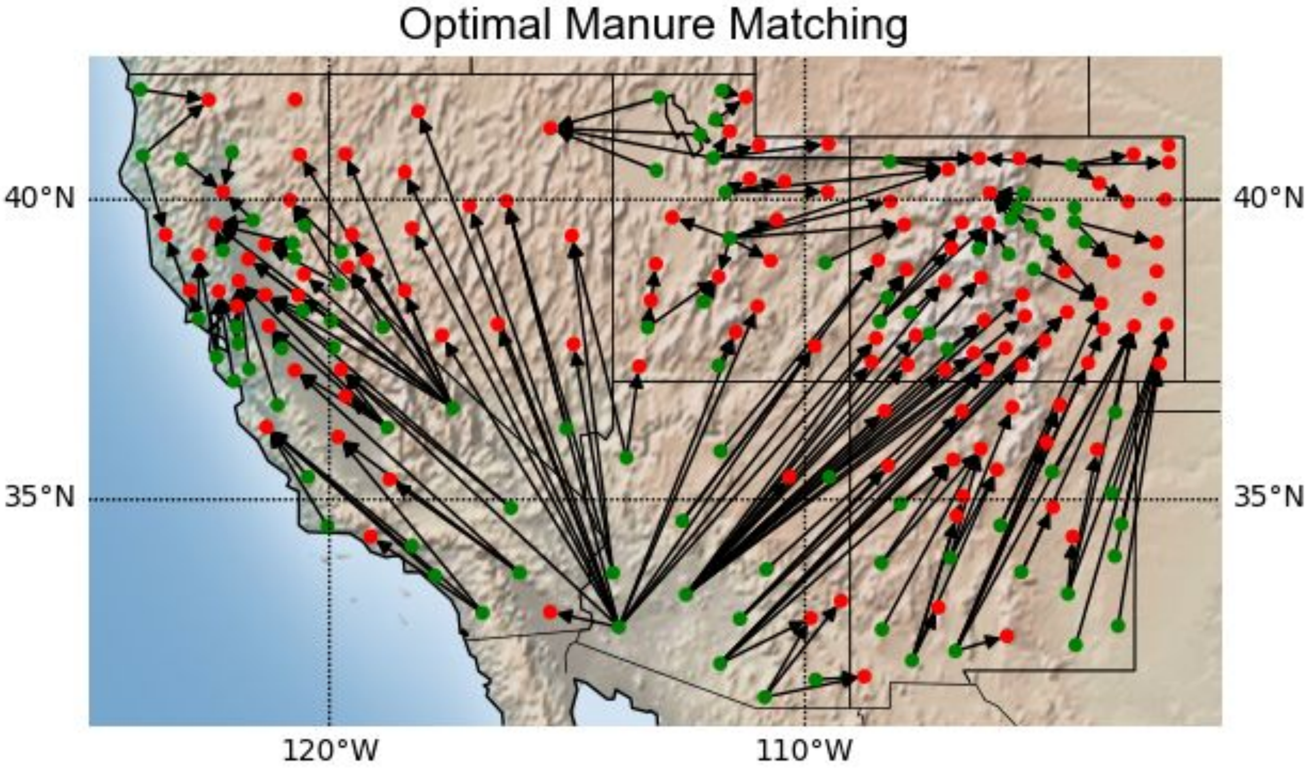
Results Summary

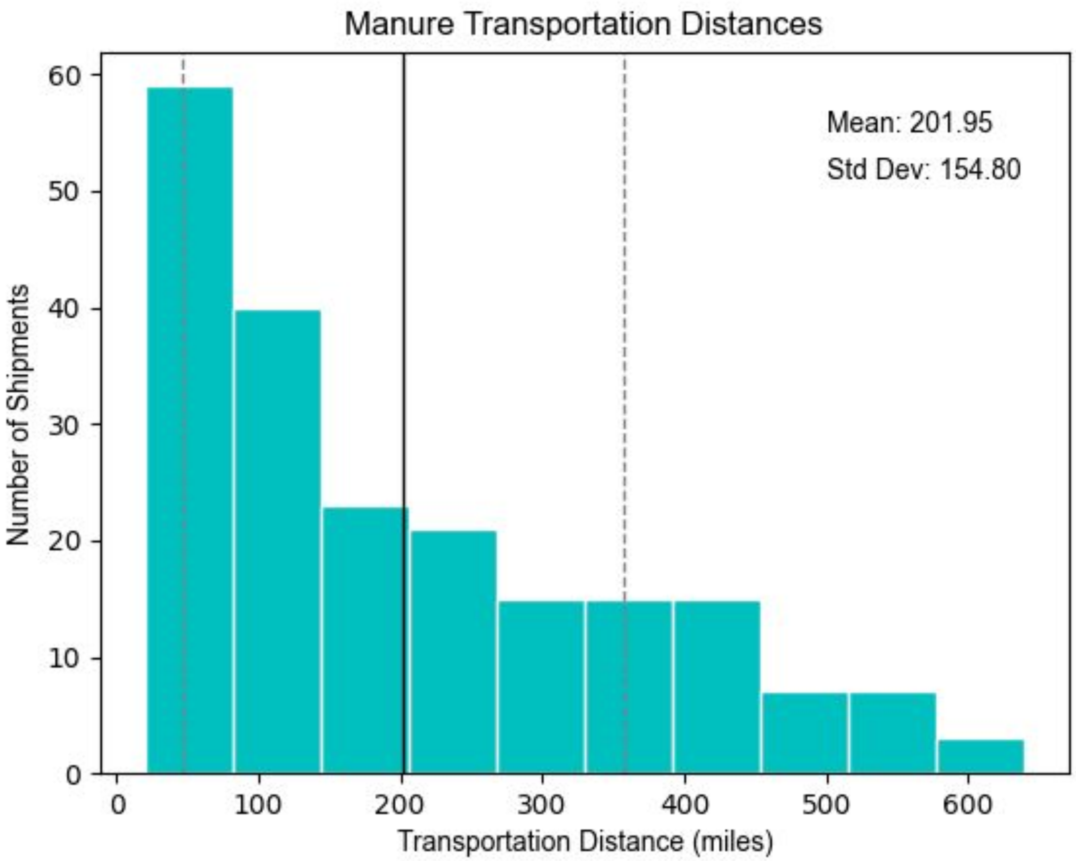
	Status Quo [2]		Least-Cost Matching	
	Weight (lbs N)	**Cost ($)**	**Weight (lbs N)**	**Cost ($)**
Manure Wasted	178,390	$ 13,148,795	43,322	$ 164,855
Synthetic Fertilizer Purchased	168,359	$ 154,890	33,292	$ 30,628
Other Costs (Transportation, etc.)	-	-	135,067	$ 330,489
Total Cost	-	$ 13,303,685	-	$ 525,972

Results Summary






Optimal Manure Matching
40°N
40°N
35°N
35°N
120°W
110°W


Manure Transportation Distances
Mean: 201.95
Std Dev: 154.80
Number of Shipments
60
50
40
30
20
10
0
0
100
200
300
400
500
600
Transportation Distance (miles)

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Conclusions

1. Significant savings possible through manure reallocation
2. In the least-cost matching solution, the majority of expense comes from transportation
3. Sources and sinks may not be matched purely by proximity due to relatively low transportation costs

Extensions & Future Work

1. Sensitivity Analysis
2. Expand geographic region of study
3. Different manure treatment options
4. Alternative objective: environmental impact optimization
5. Game-theoretic paradigm

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NSF

TEXAS
The University of Texas at Austin

THE UNIVERSITY OF TEXAS AT AUSTIN
INFEWS
SCHOLAR PROGRAM

References

1. Tan, M., Hou, Y., Zhang, L., Shi, S., Long, W., Ma, Y., ... & Oenema, O. (2021). Operational costs and neglect of end-users are the main barriers to improving manure treatment in intensive livestock farms. *Journal of Cleaner Production*, *289*, 125149.
2. IPNI, 2012. A Nutrient Use Information System (NuGIS) for the U.S. International Plant Nutrition Institute, Norcross, Georgia. Available online at http://nugis.ipni.net/. (Accessed tabular data on June 8, 2022).
3. Spiegal, S., Kleinman, P. J., Endale, D. M., Bryant, R. B., Dell, C., Goslee, S., ... & Yang, Q. (2020). Manuresheds: Advancing nutrient recycling in US agriculture. *Agricultural Systems*, *182*, 102813.
4. https://www.bts.gov/content/average-freight-revenue-ton-mile
5. https://www.reuters.com/world/us/us-manure-is-hot-commodity-amid-commercial-fertilizer-shortage-2022-04-06/
6. https://ageconsearch.umn.edu/record/24057/
7. https://www.iastatedigitalpress.com/air/article/6256/galley/6121/download/
8. https://farmdocdaily.illinois.edu/2022/04/nitrogen-fertilizer-prices-and-supply-in-light-of-the-ukraine-russia-conflict.html
9. https://www.nber.org/research/data/county-distance-database

QUESTIONS?