Yield Gap Dynamics of Rainfed Alfalfa in the United States

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Rationale of the study

- ✓ Alfalfa (*Medicago sativa* L.) is known as "Queen of Forages"
- ✓ United States (U.S.) is the largest alfalfa producing country in the world
- ✓ However, alfalfa production has been declined by 23% since last 10 years
- ✓ Alfalfa requires a relatively higher amount of water compared to other field crops and vegetables
- ✓ However, more than 65% alfalfa has been produced in rainfed condition in the U.S.
- ✓ The magnitude of yield loss due to water-limited condition is still unknown
- ✓ Thus, estimating current yield gap and identifying its determinants is crucial

Objectives

- ✓ Delineate county-specific alfalfa growing season
- ✓ Calculate optimum amount of rainfall required to obtain maximum yield
- ✓ Estimate the potential water use efficiency
- ✓ Assess the yield gap of alfalfa due to water-limited condition
- ✓ Identify the major alfalfa yield limiting weather variables

Methodology

Study area

- ✓ 12 states (>95% rainfed production area and >1% of the U.S. total rainfed production)
- ✓ 393 rainfed counties
- ✓ Covers >70% of the total rainfed alfalfa production in the U.S.

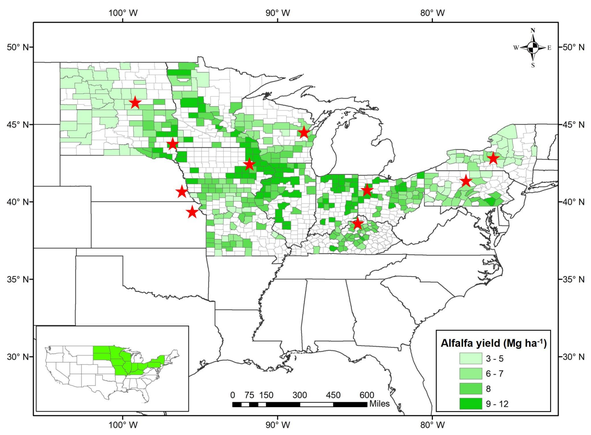

Fig 1. *Map of the U.S. showing study area. Green color represents selected rainfed counties and red star represents the location from where field experiment data were used for this study*

Methodology

Data

10-yr (2009-2018) county-level yield data obtained from USDA-NASS

10-yr (2009-2018) county-level daily weather data obtained from NOAA Regional Climate Centers

Research experiment yield data of study area during study period

Delineation of alfalfa growing season (GS)

- ✓ Number of days between last day in spring and first day in fall when probability of occurrence of GDD<0°C for each day of the year for last 10-yr is 0.2 **(Fig. 2).**

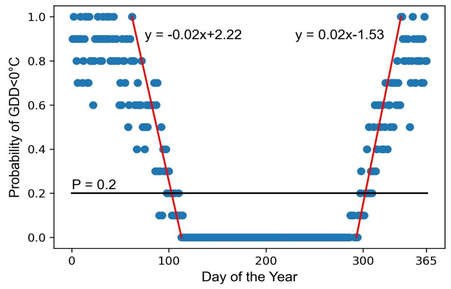

Fig 2. *Example of estimating alfalfa GS duration for Nobel county, Indiana*

Current yield (Yc)

- ✓ Farmer's reported county-level weighted average yield of the last 10 years period.

Attainable yield (Ya)

- ✓ Maximum yield that was ever achieved at a given level of growing season rainfall (GSR). It was estimated using frontier yield function (Fig 3A).

Water-limited potential yield (Yw)

- ✓ Theoretical maximum yield that can be obtained at a given level of GSR without the constraints of nutritional and other production factors. It was estimated using linear boundary function (Fig 3B).

Yield Gap (YG)

- ✓ Difference between Yc and Ya or Yw.

Yield limiting factors

- ✓ Conditional inference tree (CIT) was used to identify the major yield limiting variables (Fig 4F).

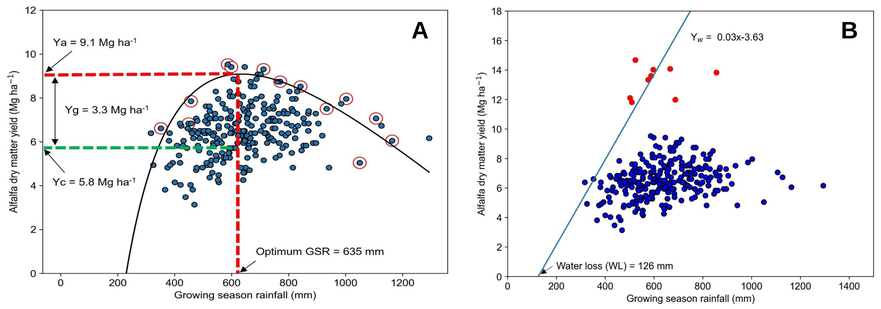

Fig 3. *Example of estimating attainable yield **(A)** and water-limited potential yield **(B)** for Wisconsin state*

Results

Growing season rainfall (GSR) and WUE

Table 1. State-level estimated GSR available water and its optimum requirement and water use efficiencies for alfalfa

State	Mean GSR (mm)	Optimum GSR (mm)	Minimum water loss (%)	Mean WUE (kg ha^{-1}mm^{-1})	Potential WUE (kg ha^{-1}mm^{-1})	% of GSR below the optimum
Illinois	746±56	759	25	10	27	27
Indiana	740±69	768	23	10	27	26
Iowa	745±45	698	24	10	31	17
Kentucky	936±92	880	23	8	27	21
Minnesota	542±119	630	14	13	34	22
Missouri	827±87	719	24	7	27	12
New York	632±59	587	24	8	34	14
North Dakota	366±40	391	21	12	27	13
Ohio	693±56	645	31	11	38	22
Pennsylvania	743±67	636	34	8	31	19
South Dakota	441±77	688	25	13	34	47
Wisconsin	648±66	635	19	10	27	15

Current yields and yield gaps

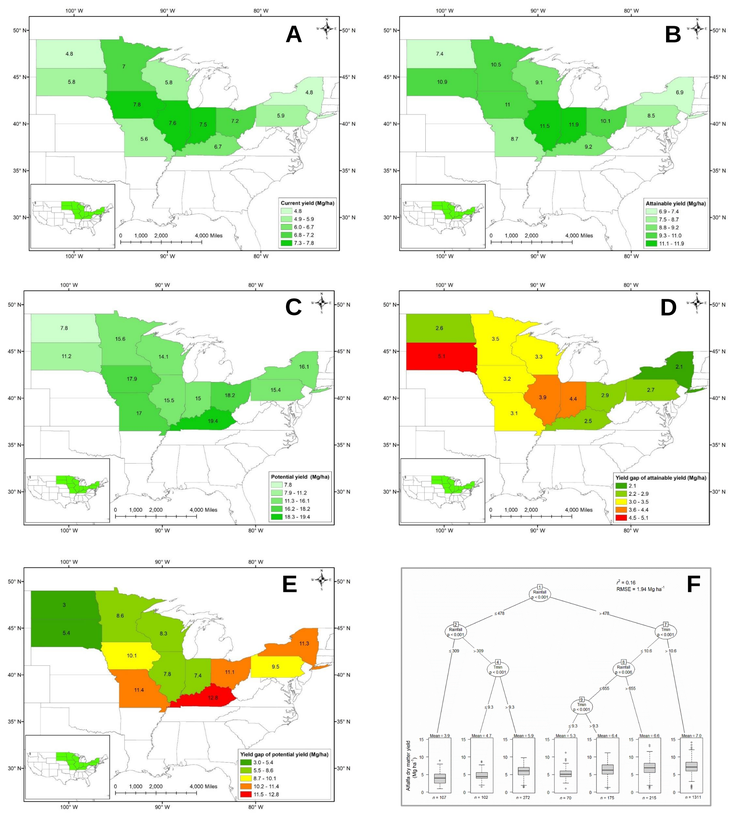

Fig 4. *Estimated state-level current yield **(A)**, attainable yield (B), water-limited potential yield **(C)**, yield gap of attainable yield **(D)**, yield gap of water-limited potential yield **(E)** and conditional inference tree showing major yield limiting weather variables **(F)***

Conclusions

- ✓ There is a wide yield gap (up to 58%) in the rainfed alfalfa growing counties in the U.S.
- ✓ Water is the main yield limiting factor for rainfed alfalfa followed by minimum temperature
- ✓ The existing yield gap could be minimized through
  - — irrigation management
  - — use of drought resistance varieties
  - — selection of cold tolerant varieties