The Alfalfa Yield Gap: A Review of the Evidence

Michael P. Russelle

Abstract
Knowledge of feasibly attainable crop yields is needed for many purposes, from field-scale management to national policy decisions. For alfalfa (Medicago sativa L.), the most widely used estimates of yield in the US are whole-farm reports from the National Agriculture Statistics Service, which are based on the farmer’s estimates of total production. These reports combine establishment-year and production-year harvests, which may inadvertently reduce yield expectations for production-year stands. However, some reported yields were unrealistically high, indicating a previously unreported problem with forage yield reports. This article presents new summaries of information from the small-plot to the whole-farm scale, which support the conclusion that dry hay yields (13% moisture) greater than 8 tons/acre are feasible under irrigation in the West and yields greater than 6 tons/acre are feasible under nonirrigated conditions in many states in the East. There is a yield gap of 2- to threefold between average and top-tier producers in most states. Bridging that gap should greatly improve farm profitability and availability of the product.

INTRODUCTION
Alfalfa has been grown in the US since the 18th century, if not earlier, and became the premier forage legume crop in the 19th and 20th centuries (9). Now grown in all 50 states for its high forage quality, alfalfa also benefits following crops (12, 18), protects water quality (10, 13), improves soil C storage (8), and reduces production of “greenhouse” gases in cropping systems (4).

Despite these benefits, alfalfa production area has declined in the past 50 years from 28.3 to 19.2 million acres, even though average reported whole-farm yields are 50 to 70% higher than in 1962 and regularly exceeded corn (Zea mays L.) grain yield until only 15 years ago (15, Fig. 1.).

Nearly the entire alfalfa crop is used as a feed for livestock and poultry. Much of the reduction in alfalfa acreage has been attributed to greater use of corn silage in ruminant diets. Compared with alfalfa, corn silage produces more dry matter and energy per unit land area, has more predictable quality,
and does not require multiple harvests (5). Value-added product streams from alfalfa, such as human-grade food protein, nutraceuticals, and cosmetics (4), have not yet proven to be economically viable. The crop is being considered as a potential feedstock for biomass-derived fuels (4, 11). This approach has been based on producing two product streams: stems, which decline with age in feed quality for ruminant diets, but which also have desirable characteristics as an industrial feedstock; and leaves, which have high and nearly constant forage quality, especially as a protein source (11).

Whatever the end use, the actual and perceived value of a crop depends, in part, on achievable economic return, which is directly related to herbage yield and quality. This is a problem for alfalfa, because the most widely used sources of crop yield information in the US, the Census of Agriculture and the Agricultural Yield Survey, provide yields that combine harvests from newly established and older, more productive stands. These whole-farm averages may disadvantage alfalfa in comparison to other crops (3).

The accuracy of alfalfa production estimates may be poor, because, although commercial hay growers determine the weight and moisture of their crop, how many alfalfa producers measure yield when the forage will be directly fed to livestock?

As the US moves toward expecting more agricultural production from a constant land base, the question of what can or should be grown for feed, food, fiber, and fuel is often answered based on yield expectations. Yield expectations also influence plant nutrient and lime recommendations, the anticipated economic return of higher-cost seed and pest control, and other management decisions, and also the calculation of lost value due to pests or weather.

What are reasonable alfalfa yield goals in the US? Four lines of evidence are used here to answer this question: 1) reports from forage specialists about what alfalfa yield levels their “top-tier” producers obtain (whole-farm scale for production-year stands); 2) yields from alfalfa cultivar performance trials (small-plot scale for production-year stands); 3) alfalfa yield distributions from the 2007 Census of Agriculture (whole-farm scale averaged over all harvested fields); and 4) on-farm yield measurements from three state-wide programs. Little alfalfa is grown in Alaska and Hawaii, so this analysis applies to the contiguous 48 US states. All yields in this paper are expressed as dry hay with 13% moisture content, to conform to the USDA-NASS reporting convention.

**LINES OF EVIDENCE**

**Top-tier Producers**

As part of data gathering for the application of alfalfa as a renewable feed stock, and with the assistance of the National Alfalfa and Forage Alliance, I conducted an on-line survey of forage specialists in Summer 2011. The specialists were asked to describe “alfalfa yield and management for top-tier US producers” and that were “typical and reasonable for high-yielding producers who are good managers of alfalfa in your area.”

Complete responses were obtained from 25 specialists in 21 states that produced 72% of total US production of dry alfalfa hay and the same proportion of total irrigated hay production in 2007. Production-year yield estimates from that survey are emphasized here. However, 70% of respondents from the East said that top-tier growers seed alfalfa in spring and harvest an average of 2 tons/acre of hay in the first growing season. All except one respondent from the West indicated that late summer/early fall seeding was typical for their top-tier producers, which means that no alfalfa harvests occurred during the seeding year.

The intent was to generate reasonable (albeit subjective) regional estimates, so responses were aggregated and will be described here for nonirrigated alfalfa in states east of about 102° W (the border of Colorado and Kansas), and the irrigated and nonirrigated systems west of that line. The mean yield for production-year alfalfa in the East was 6 tons/acre and only two of 16 respondents reported a higher or lower estimate. The estimate for irrigated alfalfa in the West was 8 tons/acre, whereas dryland alfalfa yields in the West were estimated at only 2.3 tons/acre on average.

Top-tier producers are reportedly harvesting about 45% more (range 31 to 70%) under irrigation in the West than the mean yields from the 2007 Census of Agriculture (Census mean = 5.5 t acre), only about 10% more without irrigation in the West (Census mean = 2.1 tons/acre), and more than twice as much alfalfa in the East (Census mean = 2.3 tons/acre). In the East, alfalfa stand life was reported to be 2 to 5 production years. Thus, estimated whole-farm yields for these top-tier producers, corrected algebraically for an establishment-year yield of 2 tons/acre, are 4.7, 5.0, 5.2, and 5.3 tons/acre for farms with 2, 3, 4, and 5 years of 6 ton/acre yields after the establishment year, respectively. These whole-farm estimates still greatly exceed the 2007 Census average. How likely is it that alfalfa producers can attain the yields these specialists report?
One approach to validating those estimates is to compare them with cultivar (variety) performance trials, conducted in many states to provide independent, replicated, multi-year comparisons of yield, quality, stress resistance, and persistence of commercial alfalfa cultivars and experimental lines. Here, I summarize results from the most recent published report from all locations. To reduce the effect of non-normal distributions due to one or a few high values, the geometric mean yield was calculated across the first three production years at each location. For brevity, however, I use the term “mean” hereafter. Establishment-year yield data were not consistently reported and were excluded, as were yields from check cultivars and experimental lines. For example, for a trial established in spring 2005 and completed in 2009, data were averaged from the 2006, 2007, and 2008 growing seasons. Some locations are included where only two production years were reported. In states where alfalfa cultivar performance trials have been discontinued, the most recent data are from trials conducted as long ago as the mid 1980s.

Yields reported in these trials were determined on directly chopped forage. To account for typical yield losses during hay making, mean yields were reduced by 11.5% (7). Nearly all reports were available on the internet; the editors of Crop Management provided archived reports that were no longer available on their website.

High alfalfa yields have been achieved across most of the US in these small plot trials (Fig. 2). The smallest mean yield of these trials was 1.4 tons/acre, under rainfed conditions in the semiarid climate near Moccasin, MT. All of the other 63 nonirrigated sites yielded at least 3.3 tons/acre. Of those trials in the predominantly nonirrigated region of the US (east of 102° W longitude), one-half yielded more than 6 tons/acre, with 23 yielding between 6 and 8 tons/acre, and 9 trials yielding between 8 and 9.2 tons/acre. Yields were generally lower than 6 tons/acre in the southeastern US states.

The lowest mean yield under irrigation (4.1 tons/acre) occurred at Lingle, WY. Nearly one-half of the trials under irrigation in the West yielded more than 8 tons/acre. The highest estimated dry hay yield in this set of cultivar performance trials (12.1 tons/acre) occurred in Garden City, KS.

These small-plot data support the view of the forage specialists that 6 ton/acre yields are feasible in the nonirrigated East and 8 ton/acre yields are feasible in the irrigated West. The frequency of high yields in these trials may have resulted from careful site selection and low biotic and abiotic stress. Thus, this set of yields may represent or exceed what is possible for entire fields, and certainly whole farms, in other locations.

The Census represents the most complete sampling of US farm and ranch characteristics and production. Results are collected on a whole-farm basis. Because there are concerns about the mean yields reported in the Census, I evaluated the distribution of whole-farm alfalfa yields from the 2007 Census of Agriculture for each state. A special tabulation of data was provided by NASS for harvested alfalfa in 2007, with farms categorized by total alfalfa yield in increments of 1.5 tons/acre up to 9 tons/acre, and in 3 ton/acre increments thereafter. Farm number, harvested alfalfa acres, and total alfalfa production were provided for all alfalfa, irrigated alfalfa, and nonirrigated alfalfa, each reported in dry hay equivalent (13% moisture content). The irrigated alfalfa category included farms where all or part of the crop was irrigated.

In the full dataset (290,726 farms), yields on nonirrigated land appeared to be inflated at the high end of the distribution (> 12 tons/acre). Such high hay yields are
rarely observed even in cultivar trials. This upward bias in yield reporting has not been noted before, to my knowledge. It could be due simply to inaccurate estimates of total production by the farm operator or to a misunderstanding of instructions on the Census form. Each operator was asked to report the area and total production (as dry tons) of “alfalfa and alfalfa mixtures for dry hay,” and to separately report the area and production (as green tons) of “haylage and greenchop from alfalfa or alfalfa mixtures.” Recognizing that different cuttings from the same acres may be preserved as haylage or greenchop and as dry hay, the Census form directed “…when both dry hay and haylage were cut from the same acres, report acres for each type. If two or more cuttings were made from the same acres, report acres for that item only once, but report total quantity harvested from all cuttings.” (page B-31, Appendix B of ref. 14). I speculate that some operators may not have adjusted the yield of haylage for moisture before adding it to the dry hay production weight.

To reduce this inadvertent bias, I excluded farms that reported haylage or greenchop production and those with more than 20 cattle. This subset of 142,516 farms contained far fewer instances of high yields (> 9 tons/acre) than the full Census. There was no meaningful effect on reports of high yields when the dataset was reduced further by removing farms that reported having hogs, poultry, or horses. The subset had higher (mean = 0.14 tons/acre) state average alfalfa yields than the full Census, but the difference by state ranged from −0.55 to 0.58 tons/acre. Proportions of the original total farm number remaining in the dataset ranged from 26 to 79% among states, with most of those at the low end (i.e., with the highest loss of reporting farms) being in the northern Great Plains and western Corn Belt. More specific comparisons between these two special tabulations are not available.

Despite the attempt to eliminate farms where haylage may have been added to dry hay production, 159 of 105,834 farms with nonirrigated alfalfa in the eastern US reported hay yields exceeding 15 tons/acre and 137 farms reported yields between 12 and 15 tons/acre. Comprising less that 0.3% of the farms in the dataset, these probably do not greatly affect Census reports. However, their presence raises questions about the accuracy of alfalfa yield in all yield categories, and the reason(s) behind these reports should be determined.

Cumulative yield distributions of this subset were fit to sigmoidal curves using Sigma Plot (Systat Software, Inc., San Jose, CA), which allowed frequency estimates of particular yield levels. One-half of the farms reported yields below 1.8 tons/acre in 2007 in the nonirrigated region, whereas one-half of the reports of irrigated alfalfa yield were below 3.3 tons/acre (Fig. 3). Thus, most farms produce yields much lower than the national average, which was 2.5 tons/acre and 4.5 tons/acre for nonirrigated and irrigated alfalfa, respectively. Are these low yields due to inclusion of yield data from establishment-year stands? Perhaps, but other factors likely are involved. An additional factor is the practice of grazing alfalfa fields, sometimes in combination with mechanical harvest, in many areas of the US (16). Pasture yields are not included in the Census and Survey figures. The Census and Survey are designed to document land use and total harvested production, so other initiatives may be necessary to quantify actual alfalfa production. The Census is subject to the impact of growing conditions, but yields reported in the 2007 Survey were similar to other years in that decade (Fig. 1).

At the other end of the spectrum, an estimated 11, 2.5, and 1% of eastern US farms with nonirrigated alfalfa reported yields of 4, 6, and 8 tons/acre, respectively. Under irrigation in the West, 37.5, 15, and 5% of farms reported these respective yield levels in 2007. It may prove valuable to mine the Census database for clues to the characteristics that typify these highly-productive farms.

The spatial details of these general conclusions can be seen in Fig. 4. More than 1200 producers reported yields that exceeded 8 tons/acre under irrigation in the West and more than 2700 reported yields greater than 6 tons/acre under nonirrigated conditions in the East. In general, only the top few percent of farms reported yields that met or exceeded the yield of “top tier” producers, but the numbers of these farms add credence to the claim that these yield levels are feasible.

Another way to define “feasible” yield goals is the production level achieved by a particular fraction of producers. Across the country, the top 10% of farms reported yields of at least 4.2 and 6.8 tons/acre in nonirrigated and irrigated conditions, respectively (Fig. 3). More specifically, reported hay yields of irrigated alfalfa exceeded 8 tons/acre in three states, while the remainder exceeded 4.3 tons/acre (Fig. 5). Under nonirrigated conditions, six states had yields exceeding 5 tons/acre, while most of the others exceeded 3.0 tons/
forage and grazinglands

Many of the nonirrigated results are from states where alfalfa is less well adapted, such as the southeastern US. Because alfalfa cultivar trials have been conducted in only 34 states, comparison of results from the Census and cultivar trials is best done for agricultural production regions of the US (Table 1). In only one-third of those regional comparisons did the top 10% of farms report yields equal to the cultivar trials. Thus, cultivar trials may not represent feasible yield levels in all regions, as further documented below. Using regional groups, the yield gap between the median and top 10% of farms in the Census ranged from 1.5 to 4.5 tons/acre (1.6 to 3.2 times the yield of the median farm).

**Fig. 4.** Number of farms that reported dry alfalfa hay yield (13% moisture) greater than 8 tons/acre (irrigated) or 6 tons/acre (nonirrigated), based on a subset of the 2007 Census of Agriculture. Lighter blue numbers in the typically nonirrigated region are results from irrigated alfalfa. For states with more than 50 farms with alfalfa, estimates for irrigated alfalfa were made by interpolation of best-fit sigmoidal curves. Base map courtesy of m62.net.

**Fig. 5.** Minimum alfalfa yield (13% moisture) under irrigation reported by the top 10% of farms in a subset of data from the 2007 Census of Agriculture. For states with fewer than 100 farms with alfalfa, the top 10 farms reported yields equal to or higher than the indicated yield. Base map courtesy of m62.net.
determine on-farm alfalfa yields in the 1970s and 1980s because of concerns that yields in statistical crop reports and from some farmers were “considerably below what might be expected when all production inputs are utilized” (p. 47, reference 2). These programs were designed to determine alfalfa yield potential (dry matter, protein, and energy), nutrient removal, and economic returns, and to identify and recognize top producers. Thus, these programs attracted above-average farm managers.

In Pennsylvania and Minnesota, yield of every harvest from each of the enrolled 5-acre fields was estimated by taking five to six samples of forage from forage swaths or windrows. Those yields have been adjusted to 13% moisture content for this comparison.

The highest yields recorded in 1977–89 in Pennsylvania ranged from 8.4 to 11.1 tons/acre (2). Average yields for the first 8 years were 6.2 tons/acre, 3.5 tons/acre lower than the average high yield obtained in 1977–89. For states with fewer than 100 farms with alfalfa, the top 10 farms reported yields equal to or higher than the indicated yield. Base map courtesy of m62.net.

Table 1. Estimated alfalfa yield gap (tons/acre) for agricultural production regions of the US.

<table>
<thead>
<tr>
<th>Region</th>
<th>Median of cultivar trials</th>
<th>Top 10% farms</th>
<th>Median farm</th>
<th>2007 Census Yield gap</th>
<th>2007 Census Cultivar trials</th>
<th>Top 10% farms</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hay yield (tons/acre; 13% moisture)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2007 Census</td>
<td>2007 Census</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nonirrigated</td>
<td></td>
<td>Yield gap</td>
<td>Yield gap</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Northeast</td>
<td>7.8</td>
<td>3.9</td>
<td>3.9</td>
<td>1.8</td>
<td>6.0</td>
<td>2.1</td>
</tr>
<tr>
<td>Appalachian</td>
<td>5.0</td>
<td>3.2</td>
<td>1.8</td>
<td>1.4</td>
<td>3.6</td>
<td>1.8</td>
</tr>
<tr>
<td>Southeast</td>
<td>4.2</td>
<td>3.8</td>
<td>0.4</td>
<td>1.2</td>
<td>2.9</td>
<td>2.6</td>
</tr>
<tr>
<td>Lake States</td>
<td>5.2</td>
<td>4.1</td>
<td>1.1</td>
<td>1.8</td>
<td>3.4</td>
<td>2.3</td>
</tr>
<tr>
<td>Corn Belt</td>
<td>7.3</td>
<td>4.7</td>
<td>2.6</td>
<td>2.1</td>
<td>5.3</td>
<td>2.6</td>
</tr>
<tr>
<td>Delta States</td>
<td>4.0</td>
<td>3.8</td>
<td>0.2</td>
<td>1.2</td>
<td>2.7</td>
<td>2.6</td>
</tr>
<tr>
<td>Northern Plains</td>
<td>7.6</td>
<td>4.4</td>
<td>3.1</td>
<td>2.1</td>
<td>5.5</td>
<td>2.3</td>
</tr>
<tr>
<td>Southern Plains</td>
<td>6.4</td>
<td>4.8</td>
<td>1.6</td>
<td>2.1</td>
<td>4.3</td>
<td>2.7</td>
</tr>
<tr>
<td>Mountain</td>
<td>3.1</td>
<td>2.7</td>
<td>0.4</td>
<td>1.2</td>
<td>1.9</td>
<td>1.5</td>
</tr>
<tr>
<td>Pacific</td>
<td>6.8</td>
<td>3.2</td>
<td>3.5</td>
<td>1.4</td>
<td>5.4</td>
<td>1.8</td>
</tr>
<tr>
<td>Irrigated</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Northern Plains</td>
<td>11.5</td>
<td>6.2</td>
<td>5.3</td>
<td>4.0</td>
<td>7.6</td>
<td>2.2</td>
</tr>
<tr>
<td>Southern Plains</td>
<td>7.6</td>
<td>8.1</td>
<td>–0.5</td>
<td>3.6</td>
<td>4.0</td>
<td>4.5</td>
</tr>
<tr>
<td>Mountain</td>
<td>7.3</td>
<td>6.1</td>
<td>1.2</td>
<td>2.8</td>
<td>4.5</td>
<td>3.3</td>
</tr>
<tr>
<td>Pacific</td>
<td>8.5</td>
<td>8.2</td>
<td>0.3</td>
<td>4.9</td>
<td>3.6</td>
<td>3.3</td>
</tr>
</tbody>
</table>

z Northeast = CT, DE, MA, MD, ME, NH, NJ, NY, PA, RI, VT; Appalachian = KY, NC, TN, VA, WV; Southeast = AL, FL, SC, GA; Lake States = MI, MN, WI; Corn Belt = IA, IL, IN, MO, OH; Delta = AR, LA, MS; Northern Plains = KS, ND, NE, SD; Southern Plains = OK, TX; Mountain = AZ, CO, ID, MT, NM, NV, UT, WY; Pacific = CA, OR, WA.
in those fields (1). Lowest yields recorded in those years averaged 3.6 tons/acre; whole-farm yields in the 2007 Census exceeded this on only 15% of Pennsylvania farms (Fig. 7A). The distribution of yield for the first 3 years of the program had a much higher median (5.6 tons/acre) than for the reports of whole-farm yields in Pennsylvania in the 2007 Census (1.8 tons/acre) and were mostly larger than the top 10% of Census farms (4.2 tons/acre), but did not equal those from recent cultivar trials in the state. Cultivar trials in Pennsylvania are conducted at two locations that may not provide estimations of feasible alfalfa yields, even though they provide reliable comparisons among the alfalfa germplasms.

A similar program was conducted in Minnesota. Hay yield data from the 1984 growing season (courtesy of N.P. Martin) had a median yield of 4.7 tons/acre, more than 2.5 times the median Census yield (Fig. 7B). In contrast to the Pennsylvania results, however, yields from the Minnesota program, and the top 10% of Census farms (4.9 tons/acre), and overlapped with the cultivar trials, indicating that cultivar trials provided good estimates of feasible alfalfa yield.

A third on-farm program that provides the most reliable indication of attainable alfalfa yield under nonirrigated conditions in the Upper Midwest comes from the long-term, whole-field Wisconsin Alfalfa Yield and Persistence Program (6). Fields were located across central Wisconsin and ranged in size from about 5 to 195 acres. All loads of forage were weighed and sampled for moisture content. Hay yield exceeded 6 tons/acre on at least one field in every year from 2007 and 2012 (Fig. 7C), and one produced 7.5 tons/acre in 2012. Mean yields across sites for these years (3.8 to 5.8 tons/acre) exceeded the state averages by 2.0 tons/acre, were consistently higher than the 2.4 ton/acre yields reported in Wisconsin in the 2007 Census, and 79% exceeded the 4.2 ton/acre yield achieved by the top 10% of Census farms. Cultivar trials also appear to provide reliable estimates of feasible alfalfa yield in Wisconsin.

**SUMMARY**

Although there are shortcomings in all four lines of evidence presented here, they support the conclusion that there is a yield gap of 2- to threefold between average and top-tier producers in the US. For all states for which data are available, average whole-farm data for alfalfa, such as those in the Agricultural Survey and Census of Agriculture, do not represent what a substantial number of farmers harvest from production-year stands. If yield expectations are too low, producers may be less willing to grow alfalfa in the first place or to invest in top-performing cultivars, soil amendments, nutrients, pest control, and modern equipment. They may not pay attention to harvest timing and frequency, which are major determinants of yield. Furthermore, national policies may not sufficiently credit the current and potential contributions of alfalfa to the farm and national economy.

![Fig. 7. Frequency distribution of yields (13% moisture) for the 2007 Census of Agriculture, the Alfalfa Grower Program (AGP) in Pennsylvania (A, 17) and Minnesota (B, courtesy N.P. Martin, who provided raw data), or the Alfalfa Yield and Persistence Program (AYPP) in Wisconsin (C, 6), and median yields (round symbols) at each cultivar trial location in the respective state. Median yield (Md) for each is indicated in the legend and along the horizontal axis; the black arrow indicates the 90th percentile (top 10%) of the Census subset.](image)

**Acknowledgments**

Copies of data files used for this analysis may be obtained by contacting the author at russelle@umn.edu. My thanks to the many forage specialists who lent expertise about their top-tier producers for the on-line questionnaire, and for reviews of early questionnaire drafts by Hans Jung, Garry Lacefield, William Lazarus, Daniel Putnam, Mike Rankin, and Glenn Shewmaker. I also appreciate the expert help Jenna Knoblauch, National Alfalfa and Forage Alliance, provided with constructing and editing the questionnaire. I am grateful to Robert Hood and other staff of the USDA-NASS in Washington, DC, and in Minnesota, for their willingness and patience in providing the Census data on alfalfa yields. John Baylor and Neal Martin provided data from on-farm trials. Excellent reviews, discussions, and suggestions by Craig Sheaffer, Dan Undersander, Ryan Maher, Geoff Brink, and Matt Yost improved the manuscript. The fillable US maps...
were courtesy of m62 visual communications. Mention of trade names of commercial products in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the US Department of Agriculture.

Literature Cited
17. Waters, W.K., and Baylor, J.E. (no date) Gleanings from the Pennsylvania alfalfa growing contest. (Photocopied report from J.E. Baylor’s personal files, University of Pennsylvania)