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# Evaluation of Tillage Systems for Grain Sorghum and Wheat Yields and Total Nitrogen Uptake in the Texas Blackland Prairie

H. ALLEN TORBERT[1], ELENA KRUEGER[2], DMITRY KURTENER[3], and K.N. POTTER[4]

[1]*USDA-ARS National Soil Dynamics Laboratory, Auburn, Alabama, USA;* [2]*Westminster, Colorado, USA;* [3]*Agrophysical Research Institute, St. Petersburg, Russia;* [4]*USDA-ARS Grassland Soil and Water Research Laboratory, Temple, Texas, USA*

*Recently, there has been an increased interest in cropping systems such as conservation-tillage; however, determining the best alternative between cropping system options is often complicated by disparities in research results due to seasonal variability. The economic cost of the systems further complicates the determination of the best alternative for sustainable crop production. To evaluate tillage systems using experimental data, a computer simulation approach called fuzzy multi-attributive decision-making (MAMD) can be applied. In this study, MAMD was applied to research the impact of conservation tillage and conventional tillage systems with and without raised wide beds on yield and nitrogen (N) uptake in grain sorghum and wheat for soils of the Texas Blackland Prairie. Results of yield and N uptake data for 4 years (1994–1997) indicated that the various tillage systems had merits and demerits across the different years of study. The economic conditions of the cropping systems were also utilized in the evaluation. Utilization of this technique indicated that the no-tillage cropping system with wide beds was the best tillage system of the ones evaluated.*

*KEYWORDS* *conservation-tillage system, Texas Blackland Prairie, fuzzy indicator, multi-attributive decision-making*

Address correspondence to H. Allen Torbert, USDA-ARS National Soil Dynamics Laboratory, 411 South Donahue Drive, Auburn, AL 36832, USA. E-mail: allen.torbert@ars.usda.gov

## INTRODUCTION

The development of conservation-tillage cropping systems could be important for crop production sustainability because of the potential for improvements in soil water conservation, fuel energy savings, erosion control, and government erosion control compliance regulations. Research has indicated that cropping systems utilizing conservation tillage improves soil moisture from the surface residue cover, due to both a reduction in cultivation and increased soil insulation with the residue (Bradford and Peterson, 2000). Also, the improved soil physical conditions and increased soil organic matter results in increased soil water storage (Reeves, 1994). In addition, conservation-tillage systems have been found to be very effective in reducing erosion and limiting the amount of nutrients that leave the field in sediment (Angle et al., 1984; Gilley et al., 1987). A large part of the observed effect is increased soil water infiltration with surface residues. For example, Potter et al. (1995) reported differences in runoff volume and sediment losses between a chisel tillage system and a no-tillage system, with sediment losses as much as 30-fold greater with chisel tillage. Torbert et al. (1999) reported that total sediment lost during a simulated rainfall event was reduced in conservation tillage (0.03 Mg $ha^{-1}$) compared with conventional tillage (0.67 Mg $ha^{-1}$), which resulted in a 12-fold increase in nutrient losses associated with sediment.

For these reasons, efforts were undertaken to develop conservation-tillage systems for the Vertisol soils of the Texas Blackland Prairie. Theses soils are difficult to manage because of their physical characteristics, including high shrink/swell potential, high water holding capacity, high plasticity, increased strength when dry, and a limited range of soil water content in which soil tillage can be performed (Potter and Chichester, 1993). The most common tillage system used in this region for crop production is a chisel tillage system. A management system using raised wide beds has been proposed as a conservation-tillage system for these soils (Morrison et al., 1990). Furrows between the wide beds were used as surface drainage ways and controlled-traffic lanes. However, in order for a cropping system to be adopted, it must be both reliable and profitable.

Recently, research was conducted to examine the impact of varying tillage systems and N fertility in corn (Torbert et al., 2001), grain sorghum, and wheat (Torbert et al., 2006) for Texas Blackland Prairie soils. These studies included conservation-tillage systems compared with conventional tillage systems with and without raised wide beds. The experimental findings indicated that each tillage system had merits and demerits. Differences were observed between years due to weather variability during the growing seasons. Determining the best alternative for cropping systems is complicated by this seasonal variability. The economic cost of cropping systems further complicates the determination of the best alternative for crop production due to variability in production cost between cropping systems and difference in economic returns due to yield variability. Further, studies conducted on calom (C) and nitrogen (N) cycling in these Vertisols have shown that changes in potential N mineralization levels were impacted more due to changes in tillage intensity than fertility management (Torbert et al., 1997). Therefore, study of the influence of soil tillage systems on N uptake of grain sorghum and wheat in these soils is also fundamental to determining the sustainability of the cropping system. New methodology is needed to evaluate the best alternative cropping system to utilize according to experimental data and to determine the system that would be most sustainable.

In recent years, a new methodology has been developed to evaluate diverse and variable experimental data called multi-criterion decision-making (MCDM). There is a large and growing literature base on MCDM. Carlsson and Fuller (1996) indicated four major families of methods in MCDM (Li, 1999; Wang, 2005). One line of the MCDM is multi-attributive decision-making (MADM) application for evaluation of cultivation practices was developed by Krueger and Kurtener (2003, 2007). Therefore, the problem of assessing tillage systems can utilize the fuzzy MADM approach for determining the best alternative. The objective of this study was to use the fuzzy MADM approach to examine the tillage systems according to experimental data on grain sorghum and wheat yield and total N uptake collected in the Texas Blackland Prairie.



## MATERIALS AND METHODS

### Data Collection

Data used in this analytical research was obtained from an experiment at the Grassland, Soil and Water Research Laboratory, at Temple, TX (31°05′N, 97°20′W) on a Houston Black (Fine, smectitic, thermic Udic Haplusterts) clay soil. The study was imposed on an existing tillage study consisting of no-till and chisel tillage systems that had been maintained for 8 years previous to the initiation of a N management study. Tillage plots (244 m long and 18.3 m wide) consisted of either a chisel plow tillage system with bedding (chisel-bed), chisel plow without bedding (chisel-no-bed), or a no-till system with bedding (no-till). The chisel-no bed system consisted of flail-shredding residue, tandem disking, chisel tilling, tandem disking, and field cultivating. The no-till system consisted of no pre-plant tillage and planting with a slot planter. In the chisel-no-bed and the no-till systems, the beds were raised soil areas 0.15 m high, 1.5 m wide and each was separated by 0.5 m furrows (Morrison et al., 1990). In the chisel-bed system, the beds were chisel plowed annually and then reconstructed each year. Once every three years in the no-till system, the furrows between the wide beds were maintained with a sweep that cleaned the furrow and reformed the bed shoulder.

Crop production in the experiment consisted of an annual rotation of grain sorghum followed by wheat, followed by corn. Each of the crops were present in the study each year. Grain sorghum row spacing was 76 cm and wheat was 15 cm. A starter fertilizer (10-34-0 solution) placed adjacent to the seed at planting provided 5.6 kg N $ha^{-1}$ and 43.7 kg $P_2O_5$ $ha^{-1}$ to all treatments for the grain sorghum. Yearly fertilizer N applications previous to initiation of this study were 168 kg $ha^{-1}$ applied to corn, 140 kg $ha^{-1}$ applied to grain sorghum, and 112 kg $ha^{-1}$ applied to wheat. A detailed description of this experiment results for grain sorghum and wheat is given by Torbert et al. (2006). Data selected for the fuzzy MADM analysis includes grain and fodder yield for wheat and grain sorghum. Economical assessment for the cropping systems used in this study is described by Harman et al. (1996). Economic data selected for fuzzy MADM analysis includes variable costs accounts for expenses associated with the varying cropping systems such as herbicide and fertilizer cost, while DITI cost account for expenses related to depreciation, interest, taxes, and insurance.



## Algorithm for Estimation of Tillage Systems

For assessment of tillage systems according to experimental data, we used an algorithm and program for fuzzy multi-attributive evaluation of cultivation practices (Krueger and Kurtener, 2003, 2007). The algorithm is based on the use of fuzzy indicators and the minimum average weighted deviation method (Li, 1999). Briefly, the fuzzy indicator is defined as a number in the range from 0 to 1, which reflected an estimation given by an expert and modeled by appropriate membership function. In this study, we use two types of fuzzy indicators: benefit and cost. So-called benefit fuzzy indicators are used to normalize attributes for maximization, while cost fuzzy indicators are utilized to normalize attributes for minimization (Figure 1).

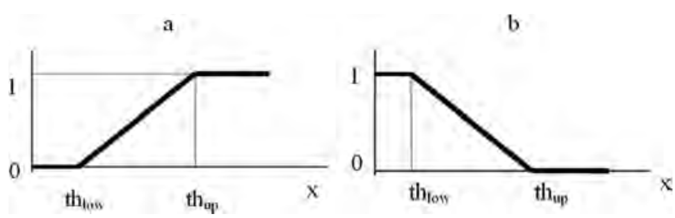


**FIGURE 1** A Benefit attribute modeled by an increasing piecewise-linear membership function (a), and a cost attribute represented by decreasing piecewise-linear membership function (b). $th_{low}$ and $th_{up}$ are reference points of $x$.

The minimum average weighted deviation method is based on the assumption that there is a so-called ideal alternative, characterized by an upper bound of all fuzzy indicators. Any real alternative is characterized by different values of fuzzy indicators. Obviously, the better alternative among the various alternatives is closer to the ideal alternative. Therefore, the lower the absolute value deviation/distance the closer it is to the ideal alternative. Absolute value deviation/distance of each alternative from the ideal alternative is used as a criteria for choosing the optimal alternative. The algorithm for estimation of tillage systems of agricultural management systems (Krueger and Kurtener, 2003, 2007) has several procedures, including problem definition, building a decision matrix, normalizing decision attributes, building a normalized decision matrix, calculation of the weight vectors of the attributes, calculation of the objective functions, ranking alternative, and definition of the best alternative.

In this study, examination of the tillage systems according to experimental data was carried out in two variants: 1) evaluation of the tillage systems using crop yield attributes and the total N uptake attributes only, and 2) evaluation of the tillage systems using crop yield attributes, the total N uptake attributes, and economic attributes.

In the first variant, crop attributes were as follows: grain sorghum grain yield, grain sorghum fodder yield, wheat grain yield, and wheat fodder yield. The first variant was realized by four sub-variants. Decision matrixes for these sub-variants are shown in Tables 1, 2, 3, and 4. In the second



**TABLE 1** Decision Matrix for Grain Sorghum Grain Yield and Total Nitrogen Uptake

| | (kg ha$^{-1}$) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Tillage System | Yield (1994) | Yield (1995) | Yield (1996) | Yield (1997) | Total N Uptake (1994) | Total N Uptake (1995) | Total N Uptake (1996) | Total N Uptake (1997) |
| Chisel-no-bed | 1933 | 2587 | 3415 | 3548 | 31.7 | 46.5 | 60.7 | 66.5 |
| Chisel-bed | 5690 | 4352 | 3638 | 3635 | 87.4 | 71.0 | 61.9 | 74.2 |
| No-till | 6221 | 3374 | 2389 | 3998 | 96.5 | 51.5 | 38.8 | 75.3 |

**TABLE 2** Decision Matrix for Grain Sorghum Fodder Yield and Total Nitrogen Uptake

| | (kg ha$^{-1}$) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Tillage System | Yield (1994) | Yield (1995) | Yield (1996) | Yield (1997) | Total N Uptake (1994) | Total N Uptake (1995) | Total N Uptake (1996) | Total N Uptake (1997) |
| Chisel-no-bed | 2099 | 2860 | 2535 | 3334 | 15.1 | 20.6 | 17.1 | 30 |
| Chisel-bed | 4580 | 4658 | 2448 | 3924 | 30.7 | 30.2 | 13.7 | 34.5 |
| No-till | 4471 | 3334 | 2489 | 5210 | 28.5 | 20.1 | 15.2 | 43.8 |

**TABLE 3** Decision Matrix for Wheat Grain Yield and Total Nitrogen Uptake

| | (kg ha$^{-1}$) | | | | | |
|---|---|---|---|---|---|---|
| Tillage System | Yield (1995) | Yield (1996) | Yield (1997) | Total N Uptake (1995) | Total N Uptake (1996) | Total N Uptake (1997) |
| Chisel-no-bed | 1807 | 1027 | 2909 | 50.8 | 29.4 | 70.7 |
| Chisel-bed | 1807 | 1500 | 2852 | 54.0 | 39.6 | 62.3 |
| No-till | 1954 | 2064 | 2578 | 54.1 | 54.0 | 56.4 |

**TABLE 4** Decision Matrix for Wheat Fodder and Total Nitrogen Uptake

| | (kg ha$^{-1}$) | | | | | |
|---|---|---|---|---|---|---|
| Tillage System | Yield (1995) | Yield (1996) | Yield (1997) | Total N Uptake (1995) | Total N Uptake (1996) | Total N Uptake (1997) |
| Chisel-no-bed | 2496 | 1145 | 2534 | 24.8 | 9.3 | 14.6 |
| Chisel-bed | 2898 | 1320 | 2887 | 31.8 | 9.7 | 16.7 |
| No-till | 3039 | 1872 | 2267 | 29.7 | 13.1 | 12.5 |

**TABLE 5** Decision Matrix for Grain Sorghum and Economical Attributes

| | (kg ha$^{-1}$) | | ($) | |
|---|---|---|---|---|
| Tillage System | Mean Grain Sorghum Yield (1994-1997) | Mean Total N Uptake (1994-1997) | Variable Costs for Grain Sorghum Yield | DITI Costs for Grain Sorghum Yield |
| Chisel-no-bed | 2870.75 | 51.350 | 209.26 | 34.23 |
| Chisel-bed | 4328.75 | 73.625 | 212.09 | 34.23 |
| No-till | 3995.50 | 65.525 | 200.62 | 27.48 |

**TABLE 6** Decision Matrix for Grain Wheat and Economical Attributes

| | (kg ha$^{-1}$) | | ($) | |
|---|---|---|---|---|
| Tillage System | Mean Grain Wheat Yield (1995-1997) | Mean Total N Uptake (1995-1997) | Variable Costs Wheat Grain Yield | DITI Costs Wheat Grain Yield |
| Chisel-no-bed | 1914.33 | 50.3 | 95.03 | 33.82 |
| Chisel-bed | 2053 | 51.967 | 97.86 | 33.82 |
| No-till | 2198.67 | 54.833 | 77.48 | 25.05 |

variant crop attributes were mean grain sorghum grain yield and mean wheat grain yield. The second variant is realized by two sub-variants. Decision matrixes for these sub-variants are shown in Tables 5 and 6. In this study, crop yield attributes and total N uptake attributes are interpreted as benefit indicators. Economical attributes (variable costs and DITI costs) are interpreted as cost indicators.

## RESULTS AND DISCUSSION

Results of the computer simulations are presented in Tables 7, 8, 9, and 10. They show that the estimates of the fuzzy indicators for the tillage systems

**TABLE 7** The Corresponding Absolute Value Deviation/Distance of Each Tillage System from the Ideal Alternative for Variant 1 (for Consideration of Crop Yield Attributes Only)

| Crop Yield Attribute | Tillage System | The Corresponding Absolute Value Deviation/distance |
|---|---|---|
| Grain Sorghum grain | Chisel-no-bed | 0.1404 |
| | Chisel-bed | 0.0336 |
| | No-till | 0.0459 |
| Grain Sorghum Fodder | Chisel-no-bed | 0.2337 |
| | Chisel-bed | 0.1208 |
| | No-till | 0.0980 |
| Wheat Grain | Chisel-no-bed | 0.2439 |
| | Chisel-bed | 0.4893 |
| | No-till | 0.6030 |
| Wheat Fodder | Chisel-no-bed | 0.0064 |
| | Chisel-bed | 0.5726 |
| | No-till | 0.2409 |

**TABLE 8** Rank of Tillage Systems for Variant 1 (for Consideration of Crop Yield Attributes Only)

| Crop Yield Attribute | Rank |
|---|---|
| Grain Sorghum Grain | Chisel-bed < No-till < Chisel-no-bed |
| Grain Sorghum Fodder | No-till < Chisel-bed < Chisel-no-bed |
| Wheat Grain | Chisel-no-bed < Chisel-bed < No-till |
| Wheat Fodder | Chisel-no-bed < No-till < Chisel-bed |

**TABLE 9** The Corresponding Absolute Value Deviation/Distance of each Tillage System from the Ideal Alternative for Variant 2 (for Consideration of Crop Yield Attributes and Economical Attributes)

| Crop Yield Attribute | Alternative of Tillage System | The Corresponding Absolute Value Deviation/distance |
|---|---|---|
| Grain Sorghum | Chisel-no bed | 0.2188 |
| | Chisel-bed | 0.0660 |
| | No-till | 0.0456 |
| Wheat | Chisel-no bed | 0.1362 |
| | Chisel-bed | 0.1217 |
| | No-till | 0 |

**TABLE 10** The Corresponding Absolute Value Deviation/Distance of Each Tillage System from the Ideal Alternative for Variant 2 (for Consideration of Crop Yield Attributes and Economical Attributes)

| Comparison of Alternatives of Tillage System and Fertilizer N Effect | Rank of Alternatives |
|---|---|
| Grain Sorghum | No-till < Chisel-bed < Chisel-no bed |
| Wheat | No-till < Chisel-bed < Chisel-no bed |



was dependent on the crop type (wheat or grain sorghum) and the annual values of crop yields and total N uptake. In particular, assessment of tillage systems for grain sorghum yield attributes and the total N uptake attributes only, indicated that the corresponding absolute value deviation/distance of the chisel-bed from the ideal alternative had the lowest value of 0.0336 (Table 7). The lower the value, the closer the alternative is to the ideal alternative. Thus, it is believed that with grain sorghum, the chisel-bed tillage system would be the best alternative. However, the corresponding absolute value deviation/distance for the grain sorghum with the no-till tillage systems were in close agreement compared to the chisel-bed and therefore the no-till variant for grain sorghum would be a very good alternative tillage system.

Output of the computer simulations in the case of the grain sorghum fodder and the total N uptake attributes only, indicated that the corresponding absolute value deviation/distance for the no-till tillage system from the ideal alternative had the lowest range value of 0.098 (Table 7). Thus, it may be inferred that the grain sorghum fodder with no-till tillage system would be the best alternative. Results of computer simulations for wheat grain yield and total N uptake attributes only indicated that the corresponding absolute value deviation/distance of chisel-no-bed tillage system had a lower-range value from the ideal alternative which was equal to 0.2439 (Table 7). Thus, it is reasonable to suggest that the chisel-no-bed tillage system was the best alternative for wheat grain production. Computer simulations for wheat fodder and total N uptake attributes only, indicated that the corresponding absolute value deviation/distance of chisel-no bed tillage system from the ideal alternative had the lowest value of 0.0064 (Table 7). Thus, it may be inferred that the chisel-no bed was the best alternative for wheat fodder production. The resulting ranking for each of the tillage systems considering the crop yield component attributes only are given in Table 8.

These results agreed with previous research by Torbert et al. (2006), which indicated that while the no-till tillage system may be the most reliable tillage system for these Vertisols, there was evidence that the effectiveness of tillage systems was dependent on the crop being produced. In particular, Torbert et al. (2006) showed that the best year for grain sorghum production occurred in 1994, with yields as high as 6221 kg $ha^{-1}$ observed with the no-till system. In this year, a significant improvement in both grain yield and fodder yield was observed with the tillage systems that utilized wide beds compared to the chisel tillage system with no bed. Also, Torbert et al. (2006) observed a significant impact of wheat in 1995 for the chisel tillage system with no raised bed having reduced fodder biomass yield production compared with the tillage systems with raised beds.

However, within a production system utilizing crop rotations, only one cropping system can be utilized. This requires that the best alternative for the rotation to be selected to determine the most sustainable cropping system. For this purpose, we utilized the fuzzy multi-attributive decision-making for the second variant evaluation of the tillage systems using crop yield and total N uptake attributes, and economical attributes.

Computer simulations considering the mean values of crop yield and total N uptake as well as economic attributes should give the most objective results. While the recent large changes in fuel and grain prices has introduced a level of uncertainty to the economic evaluation, it is believed that the fuzzy multi-attributive decision-making method allowed for an nonsubjective compilation of these factors. Results of the corresponding absolute value deviation/distance for this analysis are given in Table 9. They indicate that for the case of grain sorghum, the no-till system resulted in the lowest value from the ideal alternative of 0.0456 (Table 9). Thus, it is believed that for grain sorghum the no-till tillage system is the best alternative. However, it can also be observed that the corresponding absolute value deviation/distance for the chisel-bed tillage system was 0.0660 (Table 9). Therefore, the results indicate that the chisel-bed tillage system variant is a very good alternative for grain sorghum.

Results of computer simulation for wheat shows that the corresponding absolute value deviation/distance of the no-till system from the ideal alternative had the lowest value equal to 0 (Table 9). Thus, it is concluded that for wheat, the no-till system was the best alternative for grain production. Results for the wheat also indicated that the corresponding absolute value deviation/distance for the chisel-bed tillage system was 0.1217 (Table 9). Thus, as was observed with the grain sorghum, chisel-bed tillage system would be the next best alternative for wheat production.

The resulting ranking for both grain sorghum and wheat are shown in Table 10. Utilizing variant 2 for fuzzy multi attributive comparison, the results indicated that the no-till system was the best alternative for both wheat and grain sorghum. Thus, it can be inferred that the no-till system would be the most sustainable in the Vertisols of the Blackland Prairie. Further, it can be observed that the chisel tillage system which did not use soil bedding was the least favorable alternative for both the wheat and grain sorghum. The furrows between the beds in this type of cropping system provides both surface drainage ways and controlled-traffic lanes. The results of this study demonstrated a consistency for the soil bedding to provide a production advantage compared with the no bedding tillage systems.

## CONCLUSIONS

Estimation of tillage systems using algorithm and program for fuzzy multi-attributive comparison of agricultural management systems (Krueger and Kurtener, 2003, 2007) was carried out. According to data on grain sorghum and wheat yields and total N uptake in the Texas Blackland Prairie it was shown that no-till was the best tillage system. Also, results indicated that in these soils the use of soil beds in cropping systems could be beneficial. Results of computer simulation using fuzzy multi-attributive decision-making (MCDM) provided a procedure to summarize the experimental data obtained in previous researches. It was found that development of program software using algorithms such as fuzzy MCDM procedures would be advantageous to be applied in future studies for elaboration of problem-oriented research, especially given the growing uncertainty of fuel and grain prices.



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