Effects of Cover Crop Removal on a Cotton-Peanut Rotation

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Abstract. *The southeastern U.S. has a tremendous potential to grow a biomass crop during winter months when cash crops are not normally produced. These cover crops have proven to be extremely valuable to reduce soil erosion and improve soil quality. However, an opportunity to potentially harvest a portion of the cover crop for bioenergy purposes exists and needs to be considered to maximize the production potential of southeastern soils. An experiment was performed to determine if harvesting these cover crops could adversely affect soil properties or subsequent cash and cover crop yields. The experiment also included the effects of conducting an in-row subsoiling operation at different times of the year. Results from cone index measurements indicated that soil strength was significantly increased when the cover crop was harvested and not left on the soil surface to decompose. Not surprisingly, cotton and peanut cash crop yields declined by an average of 9% when the cover crop was harvested. Succeeding cover crop yields were also reduced by 17% due to the harvesting of previous cover crops. Conducting an in-row subsoiling operation in the fall of the year prior to planting the cover crop increased cover crop biomass by more than 18% over spring in-row subsoiling but had little impact on cash crop yields. Recommendations from this study should include a caution to producers who may want to consider their cover crops as a potential bioenergy crop. Reductions in both cash and cover crop production can result if cover crops are harvested instead of left on the surface to enhance soil quality. Additionally, scheduling a necessary in-row subsoiling operation in the fall of the year instead of waiting until the spring will improve cover crop yields.*

Keywords. *Bioenergy. Biomass, Cone index, Harvest, In-row subsoiling, Soil compaction.*

Energy sustainability for the U.S. will only be possible through utilization of many of our natural resources. This point was illustrated by Perlack et al. (2005), who considered the amounts of U.S. domestically produced biomass fuels and products that could be used to reduce the need for oil and gas imports. According to the Biomass R&D Technical Advisory Committee, a panel established by Congress to provide guidance on future directions of federally funded biomass R&D, a 30% replacement of U.S. petroleum consumption by biofuels should be achievable. To meet this requirement would require approximately 1 billion dry tons of biomass feedstock per year. Perlack et al. (2005) indicated that agricultural lands can produce almost 1 billion tons from annual crop residues, perennial crops, grains, animal manures, process residues, and other miscellaneous feedstocks without considering additional amounts from forestlands. In addition, Perlack et al. (2005) did not consider the potential contribution of as much as 30 Mg ha^{-1} from annual crops like sorghum (*Sorghum bicolor* L.) (Rooney et al., 2007), which is a highly productive, drought-tolerant species.

Other potentially important resources are winter cover crops, which could be partially or completely harvested in the spring of the year. Yield potentials of large biomass winter cover crops can be as much as 7 to 8 Mg ha^{-1} (Balkcom and Reeves, 2005; Dabney et al., 2001). These yields are certainly reduced from switchgrass (*Panicum virgatum* L.) (Cassida et al., 2005), which has yield potentials of almost 20 Mg ha^{-1}, but could be combined with sorghum to eclipse biomass yields from many perennial production systems. One of the largest advantages of cover crops for bioenergy use is that storage costs would be reduced due to spring harvest. All other agricultural crops are typically harvested in the fall of the year and need to be used immediately or stored over winter months until they are used. A winter cover crop that was harvested in spring would be immediately available for use and could likely be used during summer months until fall harvesting could again occur.

One of the largest concerns regarding harvesting of crop residues is the potential for increased soil erosion or decreased soil quality owing to the reduced amount of residue left on the soil surface (Johnson et al., 2006). These concerns are just as valid when considering winter cover crops. Much research should be conducted to determine the optimum amounts that could be harvested without depleting soil carbon or soil quality. Additionally important are the documented benefits, such as increased drought resistance and increased weed suppression, afforded to cash crops that im-

Submitted for review in October 2010 as manuscript number PM 8846; approved for publication by the Power & Machinery Division of ASABE in May 2011.

The use of trade names or company names does not imply endorsement by USDA ARS or USDA NRCS.

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mediately follow winter cover crops (Reeves, 1994). If the cover crops are then removed, would cash crop yields suffer as a result of their harvest?

Many producers may not properly manage their winter cover crops for maximum biomass production, instead thinking that the large amount of biomass may hinder spring planting of the cash crop. However, as equipment for residue management has improved, researchers have begun looking at alternate methods of increasing winter cover crop biomass. Fertilization is one management tool that some researchers have advocated as a resource to increase winter cover crop yield (Balkcom and Reeves, 2005; Dabney et al., 2001).

In much of the southeastern U.S., in-row subsoiling is a necessary management practice that often results in cash crop yield improvements of as much as 25% (Mullins et al., 1997; Raper et al., 1998; Raper and Bergtold, 2007; Touchton et al., 1989). Soil compaction caused by heavy field equipment and naturally occurring hardpan layers restrict root growth, particularly during periods of short-term drought, which is prevalent during the growing season. Loosening the soil profile with an in-row subsoiler provides for expansion of the rooting system into areas from which additional moisture can be obtained. However, the impact of this tillage operation on cover crop production is often overlooked as it is typically conducted in the spring in conjunction with planting of the cash crop.

Therefore the objectives of this study were:

- To determine the impact of harvesting cover crop biomass on cash crop yields.
- To determine the impact of harvesting cover crop biomass on succeeding winter cover crop yields.
- To determine if in-row subsoiling conducted at different times of the year might optimally benefit both cash and winter cover crop production.

Methods and Materials

The experiment was begun in the fall of 2006 by conducting in-row subsoiling and planting a rye cover crop at the Wiregrass Research and Extension Center (WGS) (31° 21′ N, 85° 19′ W) located in Headland, Henry County, Alabama, in is the southeastern part of the state. Soil on the 0.4 ha site was a Dothan soil series on a 0% to 1% slope. The plots had been converted to conservation tillage in 2003. The soil is classified as Dothan sandy loam (fine loamy, kaolinitic, thermic Plinthic Kandiudult), which is deep and well drained. The soils are typically low in organic matter and natural fertility (USDA-NRCS, 2009). The climate for this area is humid subtropical, with a mean annual air temperature of 18°C and 1400 mm annual precipitation.

Rye (*Secale cereale* L.) was used as a winter cover crop for each year from 2006-2009 and was planted with a 3.6 m no-till grain drill (Great Plains Mfg., Inc., Salina, Kans.) equipped with wavy coulters to assist with no-till establishment on 19 cm centers. The rye cover crop was sprayed with 2.3 L ha^{-1} of glyphosate and mechanically terminated using a spiral blade roller-crimper (Raper et al., 2004) two weeks prior to spring planting. Rolling is often practiced on high-biomass cover crops as a method of flattening the crop and enhancing the ability of the planter to effectively seed a cash crop. Typically, growers are advised to wait at least two weeks between cover crop termination and planting of the cash crop to allow the cover crop to completely die and prevent competition for the same available soil moisture. Cash crops consisted of a peanut (*Arachis hypogaea* L.) and cotton (*Gossypium hirsutum* L.) rotation with peanuts planted in 2007, cotton planted in 2008, and peanuts planted again in 2009. A John Deere (JD) 1700 four-row vacuum planter (Deere and Co., Moline, Ill.) equipped with no-till coulters and row cleaners was used for planting. Each plot had four 8 m rows spaced at 0.92 m. To harvest peanuts, the two center rows of each plot were inverted with a two-row digger-shaker-inverter (Kelley Mfg. Co., Tifton, Ga.). After three or four days of drying in the field, peanuts were harvested mechanically with a peanut combine (Hustler, Gregory Mfg. Co., Suffolk, Va.) equipped with a bagging attachment. A light disking operation was conducted after harvest to smooth the soil prior to cover crop establishment. Yield was determined by weighing freshly harvested peanuts from each plot in the field and adjusting for moisture content (typically 10%). Cotton harvesting was done by picking the two center rows of each plot with a JD 9910 two-row spindle harvester with a bagging attachment. The contents of the bags were then weighed, and seed cotton yield was calculated. Rye was sampled using two 0.25 m^2 frames per plot. The aboveground biomass was then oven-dried at 55°C to remove moisture and weighed to determine dry matter.

The split-plot experiment consisted of main plots where the cover crops were either harvested or left on the plots. A plot forage harvester (Carter Mfg. Co., Brookston, Ind.) was used to completely harvest the rye cover crops in the spring of the year prior to spring tillage and/or planting. This experiment was conducted at the same location as a previous experiment (Simoes et al., 2009). The plots from which the cover crop was harvested were placed on previous plots that had a cover crop maintained for four years. The plots where the cover crop was maintained were placed on previous plots that had no cover crops for four years. This was done to ensure that an unfair advantage was not given to the plots with an existing cover crop.

Subplots were various timing of in-row subsoiling, which was conducted at a 38 cm depth using a Paratill (Bigham Brothers, Inc., Lubbock, Tex.) mounted on a JD 8300 tractor equipped with a Trimble AgGPS Autopilot (Sunnyvale, Cal.) system, which has reported automatic steering accuracy of ±2.54 cm (1 in.). The timings were: (1) none, (2) in the fall after cash crop harvest and prior to cover crop planting, (3) in the spring after cover crop harvesting and prior to cash crop planting, or (4) both fall and spring. The Paratill was used in a “zone-loosening” arrangement with all four of the shanks pointing toward the center of the implement (Bigham Brothers, 2009). Each point was positioned approximately 5 cm away from the row so that the maximum disruption would occur approximately over the center of the row. No secondary tillage was performed after the in-row subsoiling operation.

Soil strength measurements were obtained with the tractor-mounted soil strength measurement system (SSMS), which included multiple probes for measurement of cone index (Raper et al., 1999). This machine acquired three sets of soil strength measurements across the row in each plot, from which cone index values were calculated. Cone index data were taken at every 0.003 m depth down to an approximate maximum depth of 0.5 m, giving 170 data points per dataset.

These data were reduced by averaging the data in 0.05 m increments. Soil moisture was taken at the time of sampling with a hand probe in 0 to 15 cm and 15 to 30 cm increments.

Data were subjected to ANOVA (MIXED procedure) using SAS (Littell et al., 1996), where they were analyzed by year due to the crop rotation. Multiple means comparisons were conducted with Fisher's protected LSD and least square means at significance level of $p < 0.1$.

Results and Discussion

Impact on Cover Crop Yield

During the first year of the experiment (2007), no differences were expected nor found in the rye biomass yield of plots that were assigned to be harvested or maintained (table 1; $p = 0.18$). This was particularly important because it indicated that the treatments from the previous experiment were not affecting cover crop production. However, differences in tillage treatments were found on rye biomass yield (table 2; $p < 0.01$), with Paratill in both fall and spring having the largest yields (6138 kg ha^{-1}) but being statistically similar to Paratill in fall (5935 kg ha^{-1}). Reduced values of rye dry matter were found for spring Paratill (4527 kg ha^{-1}), which was also greater than those measured for no-till (3002 kg ha^{-1}).

In 2008, no significant differences were found in cover crop yields due to harvesting or maintaining the cover crop (table 1; $p = 0.14$), even though maintaining the cover crop produced larger yields than on plots where the cover crop was harvested (6529 vs. 5387 kg ha^{-1}, respectively). Rye biomass yields from the various tillage treatments were significantly affected similarly to those from 2007 (table 2; $p < 0.01$), with fall Paratill (7080 kg ha^{-1}) having yields similar to those from both fall and spring Paratill (6848 kg ha^{-1}). Additionally, spring Paratill (conducted in spring 2007) had slightly reduced rye biomass yields but was still statistically similar (5962 kg ha^{-1}). Reduced values of rye dry matter were found for no-till (3944 kg ha^{-1}).

In 2009, rye biomass yields were affected by both the harvesting treatment (table 1; $p = 0.03$) and tillage treatment (table 2; $p < 0.01$). Plots where the cover crop was maintained had significantly greater yields (4683 k ha^{-1}) compared to plots where the cover crop was removed (3747 kg ha^{-1}). Fall Paratill had the largest amount of rye biomass yield (5279 kg ha^{-1}), which was statistically similar to fall and spring Paratill (5009 kg ha^{-1}) but larger than spring Paratill (3561 kg ha^{-1}) and no-till (3010 kg ha^{-1}).

A trend emerged from the data that indicated that rye biomass yields were affected by what happened to the previous spring's cover crop. Over the three-year period, average rye biomass cover crop yields were 5419 kg ha^{-1} for maintaining the cover crop, which was 17% greater than 4631 kg ha^{-1} for harvesting the cover crop. Additionally important is that the negative returns from harvesting the cover crop biomass seemed to escalate, with a 7% reduction found in 2007, an 18% reduction found in 2008, and a 25% reduction found in 2009. Producers who want to maximize their cover crop yields must recognize that there is a penalty to pay when large amounts of organic matter are removed from the soil surface.

Similarly, a trend was found over the three-year period that indicated that fall Paratill produced the greatest rye biomass yield (6098 kg ha^{-1}), which was only slightly greater than that of Paratill in both spring and fall (5998 kg ha^{-1}). However, requiring two in-row subsoiling operations (both fall and spring) would increase production costs with little improvements in crop yield. Therefore, producers who want to maximize their cover crop production should consider fall Paratill. Spring Paratill yielded 4683 kg ha^{-1}, which was greater than no-till (3318 kg ha^{-1}). Both tillage treatments showed signs of soil reconsolidation that adversely affected rye biomass yield.

Estimating the average value of the rye cover crop biomass to be \$50.60 (U.S. dollars) dry Mg^{-1} (\$46 dry ton^{-1}) and to be similar to the production cost of switchgrass (Downing and Graham, 1996) gives us the ability to determine the economic benefit of performing the Paratill operation, which is estimated to cost \$29.79 ha^{-1} (Raper and Bergtold, 2007). Performing fall Paratill would cost \$29.79 while resulting in increased value of \$140.67 ha^{-1}, for a net benefit of \$110.88 ha^{-1} to the producer. Spring Paratill would only provide a net benefit of \$39.28 ha^{-1}, while both fall and spring Paratill would provide a net benefit of \$76.03 ha^{-1}.

Table 1. Effect of harvesting or maintaining cover crop biomass on the following year's rye cover crop biomass. Lowercase letters indicate statistical significance ($LSD_{0.1}$), while absence of letters indicates lack of significance.

	Rye Biomass Yield (kg ha^{-1})			
Treatment	2007	2008	2009	Average
Harvested cover crop	4758	5387	3747 b	4631
Maintained cover crop	5044	6529	4683 a	5419

Table 2. Effect of tillage treatment on rye cover crop biomass. Lowercase letters indicate statistical significance ($LSD_{0.1}$), while absence of letters indicates lack of significance.

	Rye Biomass Yield (kg ha^{-1})			
Treatment	2007	2008	2009	Average
No till	3002 c	3944 b	3010 b	3318
Fall Paratill	5935 a	7080 a	5279 a	6098
Spring Paratill	4527 b	5962 a	3561 b	4683
Fall and spring Paratill	6138 a	6848 a	5009 a	5998

Impact on Cash Crop Yield

The 2007 peanut yield data showed a significant main effect of harvesting the cover crop (table 3; $p = 0.03$). Harvesting the cover crop from these plots resulted in a significantly reduced peanut yield of 2805 kg ha^{-1} as compared to the plots where the cover crop residue was maintained (3134 kg ha^{-1}). No differences were found in tillage treatments, although fall Paratill had the largest peanut yields (3216 kg ha^{-1}; table 4).

In 2008, the cotton yield data showed no differences in the cover crop harvesting treatments, with only slightly higher yields resulting from maintaining the cover crop (2787 kg ha^{-1}; table 3) as compared to removing it (2567 kg ha^{-1}). The tillage treatments were significant (table 4; $p < 0.01$), with the

Table 3. Effect of harvesting or maintaining cover crop biomass on the cash crop yield. Lowercase letters indicate statistical significance ($LSD_{0.1}$), while absence of letters indicates lack of significance.

	Yield (kg ha^{-1})		
Treatment	Peanut (2007)	Seed Cotton (2008)	Peanut (2009)
Harvested cover crop	2805 b	2567	2760
Maintained cover crop	3135 a	2787	2447

Table 4. Effect of tillage treatment on cash crop yield. Lowercase letters indicate statistical significance ($LSD_{0.1}$), while absence of letters indicates lack of significance.

	Yield (kg ha^{-1})		
Treatment	Peanut (2007)	Seed Cotton (2008)	Peanut (2009)
No till	3082	2163 c	2740
Fall Paratill	3216	2862 ab	2382
Spring Paratill	2858	3053 a	2521
Fall and spring Paratill	2724	2630 b	2772

Paratill treatment conducted in the spring having the highest cotton yields (3053 kg ha^{-1}). Statistically similar to the spring Paratill treatment was the fall Paratill treatment (2862 kg ha^{-1}). Slightly less was both fall and spring Paratill treatment with 2630 kg ha^{-1}. No-till had significantly reduced crop yields with 2163 kg ha^{-1}.

In 2009, peanuts were again grown in the plots but showed no impacts of either cover crop harvesting (table 3) or tillage system (table 4).

Over the three years of the experiment, some trends were noted with cash crop production, but they were not as significantly noted as with cover crop production. In two of the three years under consideration, harvesting the cover crop negatively impacted the cash crop by an average of 9%. The increased drought and weed resistance offered by a cover crop tends to have important considerations for southern crops such as peanuts and cotton (Simoes et al., 2009). If cover crops are harvested, their revenue should account for the potentially decreased cash crop yields sometimes found.

Only cotton yields were affected by tillage treatments, with spring Paratill and fall Paratill outyielding the combined Paratill treatment as well as the no-till treatment. Assuming cotton lint prices in 2008 to be \$0.7972 kg^{-1} (\$0.3617 lb^{-1}; USDA-FSA, 2008) and lint turnout to be 35% of the total seed cotton yield, the benefit of in-row subsoiling can be economically determined for cotton production. Spring Paratill proved to be the most advantageous by providing profit of \$822.05 ha^{-1} (includes the cost of Paratill treatment), which was more than \$218.53 ha^{-1} over no-till, which produced \$603.52 ha^{-1}. Fall Paratill produced \$768.34 ha^{-1}, and both fall and spring Paratill produced \$674.24 ha^{-1}.

Either spring or fall Paratill would provide enhanced revenue for cotton production, with no differences being found for peanuts. Combining the economic benefits for the cash crop with the potential for that offered for rye cover crop production indicates that fall Paratill should be the appropriate choice for most producers if they consider not only the needs of their cash crop but also their cover crop.

Impact on Cone Index

In spring 2008, cone index was significantly increased by harvesting the cover crop (fig. 1) at soil depths of 0, 5, 10, 15, 20, 35, and 40 cm. Some of the difference could be explained by small differences in soil moisture taken at the same time as the cone index data, which found 6.8% soil moisture in the plots where the cover crops had been maintained as compared to 6.4% soil moisture in the plots where the cover crop had been harvested. However, increases in soil strength in the plots where the cover crop had been harvested indicate that cash crop roots will likely have more difficulty penetrating compacted layers without significant rainfall to reduce these root-limiting conditions to less than 2 MPa (Taylor and Gardner, 1963).

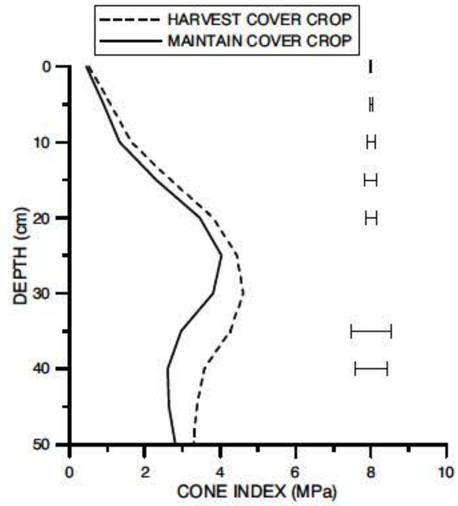

Figure 1. Effects of harvesting or maintaining the rye cover crop on cone index taken in spring 2008. Bars indicate $LSD_{0.1}$ and absence of bars indicates lack of significance.

Tillage treatments effects were also found in spring 2008, with no-till having much greater cone index values at all depths sampled (fig. 2). In-row subsoilng with the Paratill effectively removed the compacted layer down through the entire depth of tillage, which was 38 cm. The fall and spring Paratill treatment produced similar soil conditions to the fall Paratill treatment, which were both significantly reduced from the spring Paratill treatment and the no-till treatment. It is interesting to note that fall Paratill had small values as compared to spring Paratill, which had been performed more recently. One reason for the difference may have been increased infiltration during the winter months due to the loosened soil condition after the fall Paratill treatment. However, adequate soil moisture data were not taken to determine these effects.

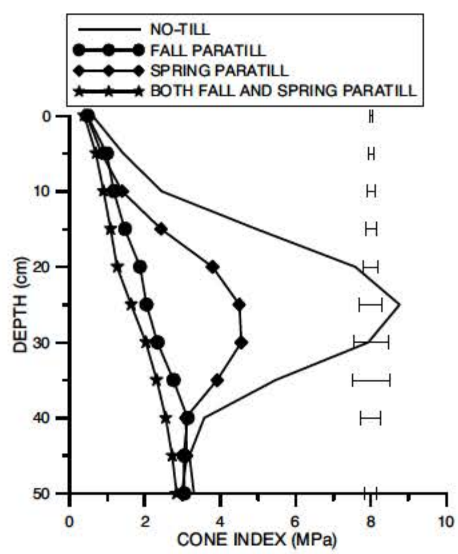

Figure 2. Effects of in-row subsoiling treatment on cone index taken in spring 2008. Bars indicate $LSD_{0.1}$ and absence of bars indicates lack of significance.

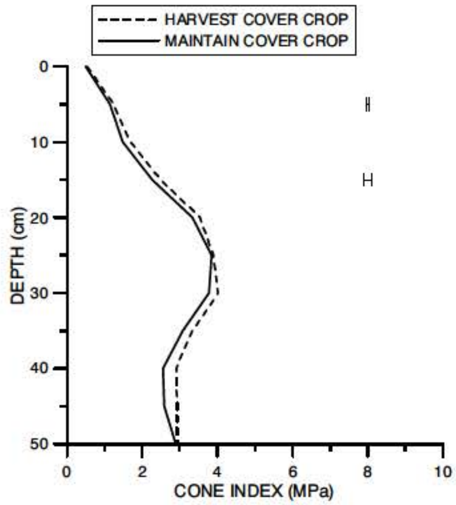

Figure 3. Effects of harvesting or maintaining the rye cover crop on cone index taken in fall 2008. Bars indicate $LSD_{0.1}$ and absence of bars indicates lack of significance.

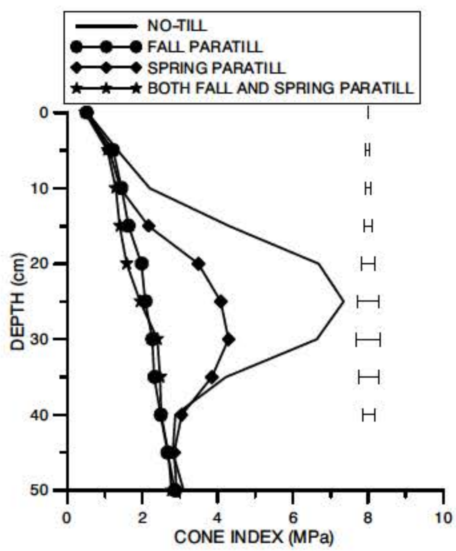

Figure 4. Effects of in-row subsoiling treatment on cone index taken in fall 2008. Bars indicate $LSD_{0.1}$ and absence of bars indicates lack of significance.

In fall 2008, differences were still noted between plots where the cover crops had been harvested and plots where the cover crops were maintained (fig. 3). However, the differences were smaller than in the spring, probably due to the deterioration of the rye biomass over the summer. Similar differences in tillage treatments were seen as in the spring (fig. 4), with no-till again having the largest values and fall Paratill and fall and spring Paratill having the smallest values throughout the entire profile. The impact of spring subsoiling does not seem to be effective to loosen soil adequately nor to produce a healthy growing condition for cover crops or cash crops.

Conclusions

A 17% reduction in rye biomass yield was found over a three-year period as a result of harvesting the cover crop. In two of the three years of the experiment, cash crop yields were decreased by an average of 9% as a result of harvesting the cover crop. Additionally, soil strength was significantly increased by harvesting the cover crop, which probably accounted for a portion of the yield reductions.

Conducting a Paratill operation in the fall of the year gave optimum yields for cover crops, cash crops, enhanced revenue, and also produced a loose soil condition throughout the growing season. No significant additional advantages of conducting another Paratill operation in the spring of the year were found on crop yields or soil condition.

Acknowledgements

The authors would like to acknowledge the great assistance provided by Mr. Karl Mannschreck, Mr. Dexter LaGrand, Mr. John Walden, and Mr. Morris Welch, who contributed to the success of this project.

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