ABSTRACT

A Baseline Study of Biofuel Feedstock Growth on Non-Traditional Agronomic Land in Utah

by

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The goal of the Non-Traditional Agronomic Land (NTAL) Project is to develop sustainable, agronomic, crop growth methods that will allow biofuel feedstock production to occur on marginal or non-traditional plots of land, e.g., roadways, railroads, airports, and military installations. Recent economic feasibility models by Utah State University (USU) indicate these lands could, in theory, produce one billion gallons of economically viable new feedstock annually. Specifically, USU models show that if 60 % (600 pounds/acre) of dry land oilseed can be produced, maintenance costs of these NTALs can be recovered, as well as production of approximately 25 gallons/acre of renewable biodiesel. This feedstock yield would increase U.S. biodiesel production between 100-200 %, and save federal and state agencies substantial financial resources.

Preliminary impact considerations that have been taken into account for production on non-traditional land include: safety, structural integrity, economics, wildlife
impacts, ecology/environmental impacts, water quality and grower concerns, soil quality, water use, generation/reduction of hazardous/toxic substances, air emissions, wastewater discharges, and reductions in use of pesticides and fertilizer.

Canola and Safflower plots were established in 2007 and 2008 along roadsides in four different regions of the Utah I-15 corridor. Harsh climatic conditions with above average temperatures and below average precipitation existed in both years. Less than 50% average yields for safflower and 25% average yields for canola under normal climatic conditions were produced. Roadside plots all yielded under 200 pounds/acre of seed for both crops. In 2008, seeds were placed 2 inches deep during planting to position them closer to moisture, and no measureable yield was observed for any crops in control plots planted on traditional farmland and less than 10 pounds/acre in roadside plots.

We found that it was not economical to grow oilseed crops for biodiesel production along Utah roadsides under the climatic conditions experienced during 2007-2008 while using a Tye Pasture Pleaser No-Till Drill.
PUBLIC ABSTRACT

Nearly all highway, airport, and military areas in Utah cost money to maintain and are often safe harbor for noxious weeds and pests. This project hypothesized that money could be saved and biofuel feedstocks could be grown in these areas, improving sustainability. Agronomic conditions and growth methods were tested to determine if biofuel feedstock production could occur on these marginal, non-traditional plots of land. Models developed illustrate that maintenance costs for these areas can be nullified if oilseed crops grown yield 600 pounds/acre and are used for biodiesel production. This feedstock yield would result in approximately 25 gallons of biodiesel feedstock/mile. Oilseed crop plots were established in 2007 and 2008 along roadsides of the Utah I-15 corridor. Prior to planting, plots areas were sampled for physical and chemical agronomic conditions and determined to be conducive (with the exception of compaction) to oilseed crop production. Plots were sprayed pre-plant with glyphosate herbicide to kill the existing vegetation. Seeds were planted using a conventional Tye Pasture Pleaser No-Till Drill. Roadside plots all yielded under 200 pounds/acre of seed for both crops both years. The experiment was repeated in 2009–2010 under similar conditions using simple modified planting methods. This modification was utilization of an Aerway aerator prior to no till planting. Maximum yields from 2009–2010 trials ranged from 600–1200 pounds of oilseed/acre. Data showed it was not economical to grow oilseed crops for biodiesel production along Utah roadsides under the climatic conditions experienced during 2007–2008 using conventional agronomic techniques, but with simple planting practice modifications, yields were raised to feasible levels in the 2009–2010 experiments. Dallas Hanks
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I would also like to acknowledge the use of the following. Without their work, I would have spent many more hours in research of the same information.

Moser (2009). Biodiesel production, properties, and feedstocks. The Society for In Vitro Biology 2009, 4,:229–266


Dallas Hanks
DEDICATION

I dedicate this dissertation to Phillip and Beulah Hanks, my mother and father, who didn’t always understand the content, but were always supportive of the effort.
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CHAPTER 1
INTRODUCTION AND LITERATURE REVIEW

Introduction

The maintenance of nearly all highway, airport, and military areas in the United States (U.S.) currently costs money, and these areas are often a safe harbor for noxious weeds and other pests (Kuhns, 1991; WSDOT, 2003). Utah alone has over 5,000 miles of highway roadsides that require maintenance, not including airport or military areas. The public cost for highway roadside maintenance—which can reach over $300 per mile—to mow, control pests, and maintain these areas each year are high (UDOT, 2007). These areas also pose the problem of noxious weed growth. A potential solution for these issues is to use these roadside areas as an agronomic resource for growing biofuel crops. With proper agronomic research, millions of acres of unused, Non-Traditional Agronomic Land (NTAL) could be put into biomass use for the production of biofuels.

The U.S. consumed over 100 billion gallons of gasoline and over 60 billion gallons of diesel in 2005 (USEIA, 2005). A majority of that energy comes from fossil fuels that are imported (60%) from other countries around the world. When these fuels are combusted, they not only release enormous amount of pollutants into the atmosphere causing disease and distress, but they add to the net carbon content of the atmosphere. In the last decade, the majority of growth in greenhouse gas (GHG) emissions came from heavy duty trucks (USEPA, 2005). The U.S. has almost four
million miles (Federal Highway Administration, 2004) of roadways that potentially could provide a billion gallons of biodiesel/year. This would result in the infusion of billions of dollars of relatively inexpensive (at current market prices) fuel into the economies of American communities and decrease dependence on petroleum based fuels. The beneficial uses of biofuels, such as biodiesel, are well documented.

**Biodiesel Fuel**

All biodiesel sold in America today must meet ASTM standards as outlined D7651 (ASTM, 2008a). Biodiesel is made with vegetable oils by transesterification with a monohydric alcohol, usually methanol (Fig 1.1; Moser, 2009).

The U.S. National Biodiesel Board estimates that the biodiesel production capacity in the U.S. for 2008 was 2.69 billion gallons per year in comparison to 23 million gallons per year in 2003 (National Biodiesel Board, 2009). Due to a renewed interest in energy sustainability and independence among energy-consuming countries, governmental mandates for alternative fuel usage and increased global production capacity all contribute to the need for alternative sources of biodiesel fuel. The U.S. Energy Independence and Security Act of 2007 includes both the first and second ruling on renewable fuels standard (RFS; EPA, 2012). RFS1—the first ruling—mandates that 11.1 billion gallons of renewable fuels are to be blended into energy supplies by the end of 2009, of which 10.5 billion gallons is to be corn based ethanol for use in gasoline. The other 600 million gallons of renewable fuels must be “advanced biofuels,” of which 500 million gallons is to be biomass-based diesel fuel (which includes biodiesel). By 2012, one billion gallons of biomass-based diesel is required under the RFS (Kotrba, 2008). The RFS2 revises the RFS1 ruling in three main aspects (Biomass Hub, 2012):
Figure 1.1. Esterification of Triacylglycerol.
RFS2 mandates that biofuels production grow from 11.1 billion gallons in 2009—the year the mandate used to benchmark volume requirements—to 36 billion gallons by 2022. This represents a 480% increase over the 7.5 billion gallon mandate under RFS1. RFS2 also caps corn-based ethanol production at 15 billion gallons and mandates that the remaining 21 billion gallons come from advanced biofuels.

RFS2 introduces the first ever greenhouse gas regulatory system in the U.S. transportation fuel industry, scoring fuels based on their upstream and downstream GHG performance. RFS1 treats all fuels equally.

Production

Biodiesel is produced by using catalysts such as sodium (or potassium) hydroxide or methoxide because the transesterification reaction is generally faster, less expensive, and more complete with these materials than with acid catalysts (Boocock, Konor, Mao, & Sidi, 1996). The majority of commercial biodiesel production is completed with methoxide (Figure 2; Zhou & Boocock, 2006), but other alcohols may also be used in the preparation of biodiesel. These include ethanol, propanol, iso-propanol, and butanol (Alamu, Waheed, & Jekayinfa, 2008; Ali & Hanna, 1994; Canakci & Van Gerpen, 2001; Dantas et al., 2007; Domingos, Saad, Wilhelm, & Ramos, 2008; Encinar, Gonzalez, Rodriguez, & Tejedor, 2002; Foglia, Nelson, Dunn, & Marmer, 1997; Freedman, Butterfield, & Pryde, 1986; Freedman, Pryde, & Mounts 1984; Georgogianni, Kontominas, Pomonis, Avlontis, & Gergis, 2008; Issariyakul, Kulkarni, Dalai, & Bakhshi, 2007; Kulkarni, Dalai, & Bakhshi, 2007; Lang, Dalai, Bakkshi, Reaney, & Hertz, 2001;
Lee, Johnson, & Hammond, 1995; Mariod, Klupsch, Hussein, & Ondruschka, 2006; Meneghetti et al., 2006; Nimcevic, Puntigam, Wurgetter, & Gapes, 2000; Peterson, Reece, Thompson, Beck, & Chase, 1996; Rodrigues, Volpato, Wada, & Ayub, 2008; Schwab, Bagby, & Freedman, 1987; Stavarache, Morris, Maeda, Oyane, & Vinotoru, 2008; Wang, Tat, & Van Gerpen, 2005; Wu et al., 1998; Yao & Hammond, 2006; Zhou, Konar, & Boocock, 2003). Butanol may be obtained from biological materials, thus yielding completely bio-based biodiesel as well (Qureshi, Saha, Hector, Hughes, & Cotta, 2008; Wahlen, Barney, & Seefeldt, 2008).

Kinematic viscosity (a measure of the resistance to flow of a fluid equal to its absolute viscosity divided by its density) is the leading reason why biodiesel has emerged as the most used diesel replacement fuel instead of vegetable oils or animal fats (Knothe & Steidley, 2005). The kinematic viscosity of biodiesel is “thinner” than typical vegetable oils or animal fats, and is slightly higher than petroleum diesel. The high kinematic viscosities of vegetable oils and animal fats can lead to engine problems such as damage to injector pumps and engine deposits from incomplete combustion.

**Advantages**

Biodiesel has many important advantages over petroleum diesel, such as lubricity (Bhatnagar, Chhibber, Gupta, & Kaul, 2006; Drown, Harper, & Frame, 2001; Goodrum & Geller, 2005; Hu, Du, Li, & Min, 2005; Hughes, Mushrush, & Hardy, 2002; Knothe and Steidley, 2005; Moser, 2008). The lubricity of Ultra Low Sulfur Diesel (ULSD)—without lubricity-enhancing additives—is 551 µm (micrometer), whereas SME (Soy Methyl Esters) has a lower value of 162 µm (Moser, 2008). The lower lubricity
value indicates superior lubricity. In additional studies, the lubricities of additive-free ULSD and SME were 651 and 129 µm, respectively (Knothe and Steidley, 2005). The reason for the poor lubricity of ULSD is the removal of sulfur-containing compounds and polar compounds with other heteroatoms, such as oxygen and nitrogen (Barbour, Rickeard, & Elliott, 2000; Dimitrakis, 2003; Knothe and Steidley, 2005). Biodiesel serves as a lubricity enhancing additive for ULSD. Lubricity is improved from 551 to 212 and 171 µm, by B2 (blend of 2% biodiesel and 98% petroleum diesel) and B20 (blend of 20% biodiesel and 80% petroleum diesel) blends of SME (soy methyl ester) in ULSD (Moser, Cermak, & Isbell, 2008).

Another important technical advantage biodiesel has over petroleum diesel is lower toxicity. Exhaust emissions are currently regulated by title 40, section 86 of the U.S. Code of Federal Regulations (CFR) which include nitrogen oxide, particulate matter, total hydrocarbons (THC), and carbon monoxide (Moser, 2009). Biodiesel combustion in diesel engines results in NOx (nitrous oxide) exhaust emissions on average of 12%, and decreases in PM (particulate matter), THC (total hydrocarbon), and CO (carbon monoxide) emissions 48%, 77%, and 48%, respectively, when compared to petroleum diesel (Graboski & McCormick, 1998; Choi, & Reitz, 1999; Environmental Protection Agency, 2002; Hess & Haas, 2007; Hess, Haas, Foglia, & Marmer, 2007; Song et al., 2002). When soy based biodiesel is blended with petroleum diesel, NOx emissions are increased by 0-4%; PM, THC, and CO emissions are reduced by 10%, 20%, and 11%, respectively (Hess et al., 2007; Environmental Protection Agency, 2002). Williams, McCormick, Hayes, Ireland, and Fang (2006) demonstrated that combustion of B5 (5% biodiesel and 95% petroleum diesel) and B20 blends of ULSD in a modern
diesel engine equipped with EGR (exhaust gas recirculation) showed no significant difference in NOx emissions from that of ULSD.

The increase in NOx emissions associated with biodiesel is of concern in areas such as national parks and urban centers. Exhaust gas recirculation, selective catalytic reduction, diesel oxidation catalysts, and NOx or particulate traps are options for the reduction of NOx exhaust emissions of biodiesel (McGeehan, 2004). NOx emissions are influenced by the chemical nature of FAAE (fatty acid alkyl ester), which constitute biodiesel. Steps that may be taken to reduce NOx emissions include:

- Increasing the chain length and/or decreasing the number of double bonds of FAAE (Knothe, Sharp, & Ryan, 2006; McCormick, Graboski, Alleman, & Herring, 2001; Szybist et al., 2005).
- Adding of 76% methyl oleate to SME (Szybist, et al., 2005).

In 2011, Ford and other manufactures solved the increased NOx emission problem by utilizing “Selective Catalytic Reduction” technology. Ford (2011) explained this technology in the following steps:

- The first step in cleaning the diesel exhaust occurs when the exhaust stream enters the Diesel Oxidation Catalyst (DOC). The role of the DOC is twofold. First, it converts and oxidizes hydrocarbons—at about 250 degrees Celsius—into water and carbon dioxide. Second, the DOC is used to provide and promote heat into the exhaust system using specific engine management strategies. Through appropriate thermal management, this heat increases the conversion efficiency of the downstream subsystem in reducing emissions.
• The second step in the process is known as Selective Catalytic Reduction (SCR). In this process the NOx in the exhaust stream is converted into water and inert nitrogen, which is present in the atmosphere and harmless. Before the exhaust gas enters the SCR chamber, it is dosed with Diesel Exhaust Fluid (DEF), also known as urea, an aqueous solution that is approximately 67.5% water and 32.5% pure urea. When heated, the DEF splits into ammonia and carbon dioxide. These molecules are atomized, broken up and vaporized, and then enter a mixer that resembles a corkscrew. This mixer evenly distributes the ammonia within the exhaust flow. The ammonia enters the SCR module, which contains a catalyzed substrate, and through chemical reactions combines and converts the NOx and ammonia into the harmless, inert nitrogen and water. Dosing typically occurs between 200 and 500 degrees Celsius.

• The final step of the cleansing system involves the Diesel Particulate Filter (DPF). The DPF traps particulate matter and periodically burns away remaining soot when sensors detect the trap is full, which is known as regenerating. The regeneration process sees temperatures in excess of 600 degrees Celsius.

With the recent higher prices for petroleum based fuels and interest in biodiesel production capacity, the world must find more biodiesel feedstock. In addition, mandates for renewable energy usage by governmental agencies around the world have necessitated the development of additional biodiesel feedstocks production capacity.
(Moser, 2009). Table 1.1 demonstrates the different molecular properties effects performance of biodiesel.

Table 1.1.

Effect of Fatty Acid Alkyl Ester structural features on melting point (mp), oxidative stability (OSI), kinematic viscosity (\(\nu\)), standard heat of combustion (\(\Delta_{\text{c}}H^\circ\)), cetane number (CN), and lubricity (Lub) (Moser, 2009).

<table>
<thead>
<tr>
<th>Structural feature</th>
<th>mp</th>
<th>OSI</th>
<th>(\nu)</th>
<th>(\Delta_{\text{c}}H^\circ)</th>
<th>CN</th>
<th>Lub</th>
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<tbody>
<tr>
<td>Chain length</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>↓</td>
</tr>
<tr>
<td>Number of double bonds</td>
<td>↓</td>
<td>↓</td>
<td>↓</td>
<td>↓</td>
<td>↓</td>
<td>↓</td>
</tr>
<tr>
<td>(cis) double bond(s)(^b)</td>
<td>↓</td>
<td>↓</td>
<td>↓(^c)</td>
<td>(\gamma^d)</td>
<td>(\gamma^d)</td>
<td></td>
</tr>
<tr>
<td>Larger ester head groups</td>
<td>↓</td>
<td>↑(^c)</td>
<td>↑</td>
<td>↓(^c)</td>
<td>↓(^c)</td>
<td>↓(^c)</td>
</tr>
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</table>

\(^a\) Higher numeric value, \(^b\) lower numeric value. For mp, \(\nu\), and lubricity, ↓ indicates that the property is improved. For OSI, \(\Delta_{\text{c}}H^\circ\), and CN, ↓ indicates that the property is negatively impacted.

\(^b\) In comparison to the corresponding trans isomer

\(^c\) Negligible or no impact

\(^d\) Effect has not been reported

Desirable characteristics of conventional and alternative oilseed feedstocks for biodiesel production include (Moser, 2009):

- Economic yields under local growing conditions (rainfall, soil type, latitude, etc.)
- Regional availability to seed and harvesting equipment
- High oil content
- Favorable fatty acid profile
- Compatibility with existing farm infrastructure and labor
• Sustainable agricultural inputs (water, fertilizer, pesticides)
• Congruent growth season
• Uniform seed maturation rates
• Potential markets for by-products
• Adjacent refining facilities to crop growth area
• Ability to grow in agriculturally undesirable lands and/or in the off-season from conventional commodity crops

The most promising alternatives to petroleum diesel fuel are biodiesel fuels prepared from feedstocks that meet a majority of the criteria listed above. Overall, algae, oilseeds, animal fats, and various low-value materials (such as used cooking oils, greases, and soap stocks) are the major biodiesel feedstock categories (Moser, 2009).

The majority of biodiesel is produced from soybean, rapeseed/canola, palm, corn, sunflower, cottonseed, peanut, and coconut oils feedstock. Biotech and advanced paradigms for use of non-traditional lands in growing biodiesel feedstock have the potential to increase the rate of yield growth for many traditional and “new” crops (Eathington et al., 2007). The following list includes many of the feedstocks utilized in biodiesel:

• *Pongamia pinnata* (Indian Beach; Naik, Meher, Naik, & Das, 2008)
• *Moringa oleifera* (Rashid & Anwar, 2008a)
• *Jatropha curcas* (Jatropha; Kumartiwari, Kumar, & Raheman, 2007)
• *Madhuca indica* (Butter Tree; Kumari, Shah, & Gupta, 2007)
• *Nicotiana tabacum* (Cultivated Tobacco; Veljkovic, Lakicevic, Stamenkovic, Todorovic, & Lazić, 2006)
• *Calophyllum inophyllum* (Punnaga; Sahoo, Das, Babu, & Naik, 2007)
• *Zanthoxylum bungeanum* (Chinese Prickly-ash; Zhang & Jiang, 2008)
• *Hevea brasiliensis* (Rubber Tree; Ramadhas, Jayaraj, & Muraleedharan, 2005)
• Heterotrophic microalgal (Miao & Wu, 2006)
• Acid oil (Haas, Michalski, Runyon, Nunez, & Scott, 2003)
• Fat from meat and bone meal (Nebel & Mittelbach, 2006)
• Brown grease 40 (Ngo, Zafiropoulos, Foglia, Samulski, & Lin, 2008)
• Waste cooking (Meng, Chen, & Wang, 2008)
• Waste fryer grease 5 (Issariyakul et al., 2007)
• Tung oil (Park et al., 2008)
• Tall oil (Demirbas, 2008)
• Sorghum bug oil (Mariod et al., 2006)
• Pork lard (Jeong, Yang, & Park, 2009)
• Rapeseed (Rashid & Anwar, 2008a)
• Sunflower (Rashid & Anwar, 2008b)
• Jojoba (Bouaid, Bajo, Martinez, & Aracil, 2007)
• Rice bran (Sinha & Agarwal, 2008)
• Waste cooking oil (Meng et al., 2008)
• *Madhuca indica* (Mahaw; Ghadge & Raheman, 2006)
• *Pongamia pinnata* (Pongam; Meher, Dharmagadda, & Naik, 2006)
• *Brassica carinata* (Ethiopian Mustard; Vicente, Martinez, & Aracil, 2005)
• Used frying oil (Leung & Guo, 2006)
• Canola (Leung & Guo, 2006)
• Cottonseed (Joshi, Toler, & Walker, 2008)
• *Raphanus sativus* (Radish; Domingos et al., 2008)

**Alternative Biodiesel Feedstocks**

Alternative Feedstock use normally occurs out of necessity where other materials are not available locally, or in an effort to reduce dependence on imported fuels. Just as important, it is the position of this dissertation that alternative agronomic land must be discovered through new technology and paradigm shifts. Examples of alternative feedstocks include:

• *Melia azedarach* (bead-tree; Stavarache et al., 2008)
• *Balanites aegyptiaca* (Desert Date; Chapagain, Yehoshua, & Wiesman, 2009)
• *Asclepias syriaca*, (Common Milkweed; Holser & Harry-O’Kuru, 2006)
• *Cynara cardunculus* (Artichoke Thistle; Encinar et al., 2002)
• *Camelina sativa* (Camelina; Frohlich & Rice, 2005)
• *Carthamus tinctorius* (Safflower; Rashid & Anwar, 2008b)
• *Sesamum indicum* (Sesame; Saydut, Duz, Kaya, Kafadar, & Hamamci, 2008)
• *Sclerocarya birrea* (Jelly Plumb; Schinas et al., 2009)
• *Cucurbita pepo* (Squash; Mariod et al., 2006)
• Melon bug (Schinas et al., 2009)
• Soybean soapstock (Haas, 2005)
• Municipal sludge (Mondala, Liang, Toghiani, Hernandez, & French, 2009)

Other Uses of Biodiesel

A number of additional applications have been developed or discovered for these versatile oleochemical materials such as:

• Replacement for petroleum as a heating oil (Mushrush et al., 2001). In the United States, blends of up to 5 % biodiesel in heating oils (B5 Bioheat) have been approved for inclusion in the ASTM heating oil standard, D396 (ASTM, 2008b).

• Fuel for generators and turbines for the generation of electricity (Hashimoto, Ozawa, Mori, Yuri, & Hisamatsu, 2008; Kalbande, More, & Nadre, 2008; Kram, 2008a; Lin et al., 2008).

• Substitute for hydrogen in fuel cells (Kram, 2008b).

• Industrial environmentally friendly solvent (Hu, Du, Tang, & Min, 2004; Wildes, 2001, 2002).

• Plasticizers in the production of plastics (Wehlmann, 1999)

• Liquid–liquid extractions (Spear, Griffin, Granger, Huddleston, & Rogers, 2007)

• Medium for site bioremediation of crude petroleum spills (Fernandez-Alvarez, Vila, Garrido-Fernandez, Grifoll, & Lema, 2006; Glória Pereira & Mudge, 2004; Miller & Mudge 1997; Mudge & Pereira, 1999).

• Starting materials or intermediates in the synthesis of fatty alcohols (Peters, 1996).
- Lubricants (Dailey, Prevost, & Strahan, 2008; Moser & Erhan, 2007; Padua, 2008; Sharma, Doll, & Erhan, 2007; Willing, 1999).
- Cold flow improver additives (Dailey et al., 2008; Moser & Erhan, 2006, 2007; Moser, Sharma, Doll, & Erhan, 2007).
- Cetane improving additives (Poirier, Steere, & Krogh, 1995).
- Multifunctional lubricity and combustion additives (Suppes & Dasari, 2003; Suppes et al., 2001)
- Contact herbicide to kill broadleaf weeds in turfgrass (Vaughn & Holser, 2007).

**Disadvantages**

Despite its many advantages as a renewable alternative fuel, biodiesel presents problems that must be resolved before it will be more attractive as an alternative to petroleum diesel, such as cost, storage, stability, energy content, and high NOx emissions.

Additives are commonly used to address fuel performance issues, and will continue until the fuel compositions are modified (Moser, 2009). The primary market for biodiesel in the near to long-term future is likely to be as a blend component in petro diesel (ULSD) at the 5-20% level as discussed previously. Soybean oil, which is currently the predominant feedstock for biodiesel production in the U.S., is expensive,
does not have an optimal fatty acid composition, has numerous competing food-related applications, and soybean seeds do not contain a high oil content.

In addition to additives, the development of alternative feedstocks, and land for feedstock production for biodiesel is another key area of research (Moser, 2009). Biodiesel already faces competition from other renewable diesel fuels such as those produced from catalytic hydrotreatment of biomass residues. From a commercial standpoint, the traditional petroleum industry may be more comfortable with these synthetic/renewable diesel fuels than with biodiesel, which may present a substantial challenge to the widespread deployment of biodiesel as an alternative fuel in the future. However, all of the environmental benefits and applications of biodiesel will continue to make it an attractive alternative to conventional petroleum diesel fuel.

**Roadside Use**

From the gravel street to the interstate highways, roads are important components of modern societies in that they provide critical corridors for transporting goods and humans. These thoroughfares occupy large portions of the land, and concern for the effects of roads on local and regional environments exists (Parendes & Jones, 2000). No matter the size, building a road disturbs the environment, and the effect on the local ecosystem is multifaceted. Issues include changes in natural water distribution, the destruction of natural habitats (through artificial wind and light), and native plant growth (with the introduction of foreign species; Angold, 1997; Brothers & Spingarn, 1992; Forman & Alexander, 1998; Gelbard & Belnap, 2003; Heilman, Stritthold, Slosser, & Dellasala, 2002; Parendes & Jones, 2000; Spellerberg, 1998; Westbrooks, 1991; Wilcox,
Additionally, heavy metals and chemicals such as carbon dioxide, nitrogen oxide, ozone, and ethylene can also be introduced through equipment usage (Atkins, Trueman, Clarke, & Bradshaw, 1982; Ball, Jenks, & Aubourg, 1998; Davison, 1971; Kammerbauer et al., 1986; Rutter & Thompson, 1986). Baker (1965) summarized the ecological attributes of roadsides as “(i) disturbed habitats; (ii) planted with non-native species; (iii) forming discontinuous vegetation patterns with adjacent sites; (iv) perpetually maintained in an early successional stage; (v) consisting of extensive edge habitats; (vi) having high light intensities; and (vii) used as transportation routes by humans and animals” (p. 130).

When building or maintaining a road, soils in the working footprint are always disturbed. Although replacement topsoil specs are usually agronomically sound, they are almost always inadequate in depth and plant root growth may be restricted due to compaction of the original soil profile (Miller, Sencindiver, & Skousen, 2002). Rentch et al. (2005) said, “The resultant roadsides are highly disturbed habitats characterized by plant communities maintained at an early successional stage. They are often planted with non-native species and frequently provide vectors for the introduction and spread of invasive species. Public transportation managers need to balance the rapid revegetation of roadsides with the goal of maximizing use of native species and minimizing the introduction of non-native species” (p. 129).

There is a growing awareness but limited efforts to develop management approaches that integrate road maintenance with vegetation maintenance by using asset management, geographic information systems, and other tools (Webb, 2003). There are also a number of U.S. states where efforts are being made to develop vegetation maintenance approaches that focus on the life-cycle costs and benefits of establishing particular plant communities (Brown & Rice, 2001; Bruneau, Cooper, Yelverton, &
Bowman, 1999). To date, none have adopted a roadside maintenance with a biofuel feedstock component model.

In the Western region of the United States, in an effort to reduce herbicide usage along roadsides, California’s Department of Transportation (CALTRANS) and University of California—Davis have studied the effects of native grasses in California roadside environments (Brown & Rice, 2001; Young, 2004). CALTRANS (2012) has also developed a resource it calls the “roadside management toolbox,” which it is using to compare different alternative practices. This toolbox offers an approach to roadside vegetation management that could help other DOT’s around the country approach this problem. In addition, Maine, Minnesota, New York, Oregon, and Vermont are reviewing their vegetation control techniques and experimenting with alternative methods (Burnham, Prull, & Frost, 2003; Edgar, 2000; Johnson, 2000; LaRoche & LaRoche, 2001; Varland & Schaefer, 1998; Williams, 2003).

Soil enhancement, vegetation control, and the establishment of desirable species at the pavement edge have been linked to compost use by many state agencies (Hamilton, Bell, Giblin, Wolf, & Ewing, 1998). Compost and soil bioengineering were studied in relation to their cost effectiveness by Hagen et al. (2002). Iowa’s DOT studied the effects compost had on roadside soil conditions and stormwater runoff (Glanville, Richard, & Pearsyn, 2003). Kirchhoff, Malina, and Barrett (2002) also conducted a compost feedstock and quality study along roadsides in several states. Based on these studies, it is conclusive that compost is useful in roadside soil enhancement and stabilization, and the addition of compost will allow for soil organic type amendments to be placed into a harsh growing environment. This will increase soil water holding
capacity, nutrient retention, availability, air movement into the soil, and provide a bank of micro and some macro nutrients.

The topic of weed management is prevalent in the literature. Alternative methods for weed control have varied from steam to “wet infrared” technology and different species of plants (Burnham et al., 2003; Edgar, 2000). Several studies have looked at alternative vegetation along the roadside environment to help in the control of weeds, including the use of crown vetch in Maine (Hamilton et al., 1998; LaRoche & LaRoche, 2001)

With roadside maintenance budgets being scrutinized more closely for savings while still demanding productivity, the idea of using roadsides lands as a biofuel feedstock production area is timely. Weed control, soil enhancement to increase productivity of these areas, decreased mowing, and pesticide application costs are all areas of cost reduction that can be applied to roadsides by growing biofuel feedstocks.

The United States has almost four million miles of roadways (Federal Highway Administration, 2004) that could potentially provide billions of gallons of biodiesel annually. This would result in an infusion of billions of dollars of relatively inexpensive—at current market prices—fuel into the economies of American communities, with particular emphasis on rural America.
CHAPTER 2
FINANCIAL INFORMATION

Introduction

The Non-Traditional Agronomic Land (NTAL) model demonstrates that maintained non-traditional agronomic land can become a financial benefit to stewards rather than a loss. Collection, transportation, and storage of feed stocks will utilize conventional equipment, which provides for a rapid transition of this technology to the public sector and successful implementation within 3 to 4 years. If applied nationally, this strategy would, in theory, produce financially viable feedstock sustainably displacing approximately one billion gallons of conventional diesel fuel per year, and the resultant carbon emission.

Financial models based on glyphosate resistant winter canola production show feasible production of ≈300 gallons of biodiesel per mile, given approximately 2/3 dry land yield in a growing area totaling 100 feet in width along roadways. This yield appears to be sustainable with as little as 14 inches of precipitation per year. Financial models show this can save the Utah Department of Transportation (UDOT) the $300 per mile which they would normally spend in mowing alone (assume petroleum diesel costs above $3.00/gal and yields of 6 cwt/acre). The vast difference in cost between private agricultural models and the NTAL model include land, insurance, overhead, and customized application of pesticides. To date, most roadside areas grow grasses, weeds, or some non-oil producing plant to control dust and erosion. These plant materials were not studied in this project because of technological limitations in the
refining of these feedstocks. In the future, said feedstocks may be used for cellulosic ethanol production or thermal transformation into useable forms of energy.

UDOT consumes approximately one million gallons of petroleum diesel per year for use in equipment such as snow removal equipment, tractors, graders, loaders and other diesel powered equipment. If the 5000+ miles of UDOT maintained roadsides could support 300/gallons of biodiesel per mile, the NTAL method of biodiesel production would produce enough biodiesel annually to run UDOT’s fleet given the assumptions listed above. Due to topographical, climatic and agronomic barriers, this may not be possible. This research was not in the scope of the current study and future studies need to be conducted to assess total NTAL suitable lands along UDOT’s roadsides. Of those areas useful for the NTAL model, this paradigm would be a new frontier for the growth of biomass utilized for biofuels. Growth of oilseed crops along freeways and coupled with the production of ethanol from the remaining biomass residues presents a new frontier in renewable energy production. This procedure would add to transportation resources and disseminate healthy, clean burning fuels into local communities along with the creation of jobs in rural areas.

Calculation Metrics for Model

The financial feasibility of the NTAL model is outlined in Table 2.1. Calculations associated with the costs of producing B100 (100% biodiesel) are detailed in the table. Footnotes following the table explain the calculations necessary for the financial model.

Formulas for calculations used in Table 2.1

- B100 sales/acre = number of gallons of oil produced/acre × market value of petroleum diesel
- Meal sale = \((\text{yield lbs/acre} \times (1 - \text{oil yield}) \div 2000) + (1 - \text{extraction efficiency}) \times (\text{yield per acre} (0.97 - \text{oil yield}) \div 2000)\)
- Total Revenue/Acre = B100 sales/acre + Meal sale
- Pressing costs = oil/acre gallons \times \text{market rate for pressing} ($0.50)
- Refining Costs = oil/acre gallons \times \text{market rate for refining} ($0.80)
- Fuel Tax Credit = B100 sales /acre \times \text{(current tax credit per gallon} ((\$1.00)) \times -1
- Total Processing Costs = Pressing costs + Refining Costs + Fuel Tax Credit
- Total Operating Costs = seed + fertility inputs + herbicide + pesticide + fertilizer/pesticide application costs + drilling + harvesting + hauling of seed + misc. costs
- Total Cash Ownership Cost/Acre = General Overhead + Management Fee
- Total Production Costs/Acre = Total Operating Costs/Acre + Total Cash Ownership Cost/Acre
- Total Costs (Processing and Production) = Total Production Costs/Acre + Total Processing Costs
- Fuel Production Profit/Acre = Total Revenue/Acre – Total Costs
- Integrated Profit/Acre = Maintenance Savings ($30/acre saved on mowing + Fuel Production Profit/Acre)
- Integrated Profit/mile = Integrated Profit/Acre \times \text{Acres/Mile}
- Cost of Production/gallon = (Total Costs (Processing and Production))
- Integrated Profit/mile = Integrated Profit/Acre \times \text{Acres/Mile}
- Cost of Production/gallon = (\text{Total Costs (Processing and Production) - Integrated Profit/Acre}) \div \text{B100 production/acre}
- Oil/acre gallons = ((\text{yield lbs/acre} \times \text{oil yield}) \times \text{extraction efficiency}) \div \text{weight of oil/gallon lbs}
- Acres of growing area/mile = \text{width of growing area(ft) \times 5280 ft \div 43560 ft}^2
• Width of growing area(ft) = width of growing area available along roadside – inclusive of shoulder and median areas

• Fuel tax credit = the volumetric excise tax credit for Agri-Biodiesel is $1.00 per gallon

• Weight of oil per gal ≈ 7.6 lbs/gallon

• Seed oil content (percent) = amount of total oil by mass in seed

• Extraction efficiency (percent) = amount of oil actually extracted from the seed

• Value of meal/ton = market value (canola meal is one of the most widely used protein sources in animal feeds; Newkirk, n.d.)

Assuming $3.08/gallon biodiesel production costs, 40% average oil content, 87% extraction efficiency, $200.00 per ton of meal for livestock feed, 6 cwt of oilseed yield; a private contractor would have an integrated profit of $10.83/acre utilizing the NTAL model. This calculation is intended to show near breakeven values for the contractor assuming that he/she would increase yields above this point. With this method, UDOT would realize a $273.00 (9.1 acres * $30/acre) savings/mile assuming this area is maintained. Oilseed yields can affect this profit up or down respectively.

Table 2.2 illustrates a break even matrix with two variables, petroleum fuel costs and oilseed yield per acre. The table includes a range of $2.00/gal and 700 lbs/acre to $4.00/gal and 2100 lbs/acre of oilseed production per acre scenarios. On the high end of
Table 2.1
Utah NTAL Financial Model–Private Contractor, Aerator and Biosolids/Nitrate Fertility

<table>
<thead>
<tr>
<th>Estimated Costs and Returns - Oilsed Production/Acre on Roadsides</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Revenue/Acre</th>
<th>Units</th>
<th>Number</th>
<th>$/Unit</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>B100 sales/acre (97% oil to biodiesel conversion)</td>
<td>gallons</td>
<td>26.0</td>
<td>3.50</td>
<td>$93.27</td>
</tr>
<tr>
<td>Meal sales</td>
<td>tons</td>
<td>6.20</td>
<td>200</td>
<td>$40.45</td>
</tr>
<tr>
<td><strong>Total Revenue/Acre</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>$133.72</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Safflower Production and Processing Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processing Costs</td>
</tr>
<tr>
<td>Pressing costs</td>
</tr>
<tr>
<td>Refining costs</td>
</tr>
<tr>
<td>Fuel tax credit</td>
</tr>
<tr>
<td><strong>Total processing costs</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Production Operating Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seed</td>
</tr>
<tr>
<td>Fertilizer from Biosolids - NPKS</td>
</tr>
<tr>
<td>Fertilizer from Fertilizer N, P, K</td>
</tr>
<tr>
<td>Herbicide - glyphosate 20 oz 41%</td>
</tr>
<tr>
<td>Pesticide - other</td>
</tr>
<tr>
<td>Fertilizer/pesticide application</td>
</tr>
<tr>
<td>Drilling, no-till</td>
</tr>
<tr>
<td>Harvesting</td>
</tr>
<tr>
<td>Hauling to Depot (100 mile radius, 1 way, bwt 42 lbs)</td>
</tr>
<tr>
<td>Misc.</td>
</tr>
<tr>
<td><strong>Total Operating Costs/Acre</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Production Fixed Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Overhead</td>
</tr>
<tr>
<td>Management Fee</td>
</tr>
<tr>
<td><strong>Total Cash Ownership Costs/Acre</strong></td>
</tr>
</tbody>
</table>

| Total Production Cost/Acre | | **$113.82** |
| Total Costs (Processing and Production) | | **$122.89** |

| Fuel Production Profit/Acre | | **$10.83** |
| Integrated Profit/acre | | **$40.83** |
| Integrated Profit/mile | acres/mile | 9.1 | $40.83 | **$412.03** |
| Cost of Production/gallon | | | | **$3.08** |

Footnotes:
- Integrated Profit/Acre = Maintenance Savings ($30/Acre saved on mowing + Fuel Production Profit/Acre) = $30 + $3.83
- Integrated Profit/mile = Integrated Profit/Acre * 9.1 acres/mile = 9.1 * $40.83 = $412.03/mile
- Cost of Production per gallon = (Total Costs - Integrated Profits per acre) / B100 sales per acre = ($129.69 - $33.89) / 26.6

*Custom Farming Values are rates expected to be charged or paid, including fuel and labor. The average price for diesel fuel was assumed to be $2.75 per gallon. A fuel price increase of $0.50 per gallon will cause total machinery costs to increase approximately 5 percent. Actual custom rates may vary according to availability of machinery in a given area, timeliness, operator skill, field size and shape, crop conditions, and the performance characteristics of the machine being used.
the matrix, petroleum fuel at 4.00/gal and yields of 2100 pounds of oilseed/acre would
give an almost 10X profits to the private contractor.

The current NTAL model relies uniquely on the assumptions that inexpensive
biosolids will be utilized for fertility inputs and soil conditioning. The model also assumes
that a $1.00 per gallon tax credit will be available to help reduce costs of refining.
Without these two key factors, production of oil seed must be increased in order to make
the NTAL financially feasible or attractive to private contractors. Without increased
yields, Table 2.2 illustrates a negative bottom line to the contractor of -$15.82/acre when
the tax credit for refining is not applied. An increase in yield to 702 lb/acre would bring
the profit back to a positive $0.13/acre. Obviously, no contractor will be able to operate
on this profit margin. If the tax credit is not renewed by Congress, UDOT would most
likely have to subsidize the NTAL model of production with the savings from
maintenance costs to make roadside production of oilseed crops for biodiesel attractive
to private contractors.

### Table 2.2

**Break Even Matrix for NTAL Areas**

<table>
<thead>
<tr>
<th>Profit/Mile Matrix (assuming 300/mile maint. fees have been retained by UDOT)</th>
<th>700</th>
<th>900</th>
<th>1100</th>
<th>1300</th>
<th>1500</th>
<th>1700</th>
<th>1900</th>
<th>2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>fuel costs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$2.00</td>
<td>-446.18</td>
<td>-224.36</td>
<td>-2.55</td>
<td>-219.27</td>
<td>-441.09</td>
<td>-662.91</td>
<td>-884.73</td>
<td>-1,106.55</td>
</tr>
<tr>
<td>$2.25</td>
<td>-358.03</td>
<td>-108.45</td>
<td>139.12</td>
<td>-396.70</td>
<td>-934.27</td>
<td>-818.85</td>
<td>-1,129.42</td>
<td>-1,377.00</td>
</tr>
<tr>
<td>$2.50</td>
<td>-265.88</td>
<td>-7.45</td>
<td>280.79</td>
<td>-554.12</td>
<td>-827.45</td>
<td>-1,100.79</td>
<td>-1,374.12</td>
<td>-1,647.45</td>
</tr>
<tr>
<td>$2.75</td>
<td>-175.73</td>
<td>123.36</td>
<td>-422.45</td>
<td>-721.55</td>
<td>1,020.64</td>
<td>1,319.73</td>
<td>1,618.82</td>
<td>1,917.91</td>
</tr>
<tr>
<td>$3.00</td>
<td>-85.58</td>
<td>-239.27</td>
<td>564.12</td>
<td>-989.97</td>
<td>1,213.82</td>
<td>1,538.67</td>
<td>1,863.52</td>
<td>2,188.36</td>
</tr>
<tr>
<td>$3.25</td>
<td>-4.58</td>
<td>355.18</td>
<td>-705.79</td>
<td>1,056.39</td>
<td>1,407.00</td>
<td>1,757.61</td>
<td>2,108.21</td>
<td>2,458.82</td>
</tr>
<tr>
<td>$3.50</td>
<td>-94.73</td>
<td>471.09</td>
<td>-847.45</td>
<td>1,223.82</td>
<td>1,600.18</td>
<td>1,978.55</td>
<td>2,352.91</td>
<td>2,729.27</td>
</tr>
<tr>
<td>$3.75</td>
<td>184.88</td>
<td>587.00</td>
<td>-989.12</td>
<td>1,391.24</td>
<td>1,793.36</td>
<td>2,195.48</td>
<td>2,597.61</td>
<td>2,999.73</td>
</tr>
<tr>
<td>$4.00</td>
<td>275.63</td>
<td>702.91</td>
<td>1,130.79</td>
<td>1,556.87</td>
<td>1,966.55</td>
<td>2,414.42</td>
<td>2,842.30</td>
<td>3,270.18</td>
</tr>
</tbody>
</table>
Results and Discussion

Several different scenarios to growing, harvesting and processing biodiesel feedstock have been examined. They include fully integrated state operated solutions, and a public-private integration with both organic and inorganic fertility variables.

Table 2.3 shows the results of each relative to savings/profit per mile utilizing NTAL maintenance cost reduction methods. State operated systems do not access the 1.00/gallon excise tax credit option offered to private growers. Biosolid fertility inputs on both state operated and public/private relationships dramatically increased savings/profit per mile.

Table 2.3
Savings/Profit Comparison of State Operated vs Private Operated NTAL Maintenance

<table>
<thead>
<tr>
<th>Profit Comparison of Tax Credit and Fertility Inputs</th>
<th>Profit/acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>tax credit + conventional fertility</td>
<td>-$29.17</td>
</tr>
<tr>
<td>tax credit + biosolids fertility</td>
<td>$40.83</td>
</tr>
<tr>
<td>no tax credit + conventional fertility</td>
<td>-$55.82</td>
</tr>
<tr>
<td>no tax credit + biosolids fertility</td>
<td>-$15.82</td>
</tr>
</tbody>
</table>

*assumptions: petrol diesel at 3.50/gal, 75 ft growing area, $1.00/gal tax credit, 600 lbs/acre*
Figure 2.1 shows the majority of savings compared to conventional growth of oilseed crops utilizing NTAL methods. Major savings include land costs, taxes, interest and insurance.

![Major Economic Differences of UDOT Land vs Private Land Oilseed Production (FY 2006)](image)

Figure 2.1. *NTAL Financial differences between conventional and NTAL costs.*

**Conclusion**

Decreased maintenance costs were the primary goal of the NTAL model. In addition, other benefits have emerged including:

- Lower carbon footprint
- Increased sustainability
- More acreage for biofuel feedstock production
- Lower emissions from increased biofuel use
- Decreased dependence on foreign energy sources
- Decreased trade deficit
- Job creation
• Distributed energy sources
• Increased public awareness of renewable energy
• More public/private interactions between land stewards and contractors

With the information elucidated above, the private contractor utilizing inexpensive public biosolids for fertility brings the most total savings/profit for the parties involved in both the state operated and public/private scenario. Using inexpensive municipal biosolids for fertility inputs decreases the cost of NTAL produced biodiesel and will enhance soil properties along roadsides. UDOT can potentially save 1.7 million dollars per year in maintenance fees (at $300/mile) by public/private relationships that produce 600 lb of oilseeds/acre. Private contractors will profit $10.83/acre given the same assumptions. A total savings/profit per mile for the public/private relationship would be >$400/mile.
CHAPTER 3
AGRONOMIC CONDITIONS ALONG UTAH ROADSIDES

Introduction

Current US public policies combined with global demand for low-carbon fuels have created a strong market for more sustainable advanced biofuels, particularly biodiesel. However, according to Don Scott, Sustainability Director for the National Biodiesel Board, “70% of the [US] biodiesel plants…are sitting idle because of the lack of affordable feedstock” (personal communication, February 2009).

The goal of this study is to develop sustainable, agronomic crop growth methods that will allow biofuel feedstock production to occur on marginal or non-traditional plots of land (e.g., roadways, railroads, airports, military installations). Recent financial feasibility models by Utah State University (USU) indicate that agronomic lands in the United States could, in theory, produce one billion gallons of financially viable feedstock annually. Specifically, USU models show that if 60% (700 pounds/acre) of a standard agronomic yield of dry land oilseed can be produced, maintenance costs of these non-traditional agronomic lands (NTAL) can be recovered as well as production of approximately 30 gallons/acre of renewable biodiesel.

With proper agronomic research, millions of acres of unused NTALs can be put into biomass production for the production of biofuels. This feedstock yield would increase U.S. biodiesel production between 100-200%, and save federal and state agencies substantial financial resources. Preliminary impact considerations that have been taken into account for production on non-traditional land include safety, structural
integrity, financials, wildlife impacts, ecology/environmental impacts, water quality, soil quality, water use, generation/reduction of hazardous/toxic substances, air emissions, wastewater discharges, reductions in use of pesticides, fertilizer, and others.

The current barrier to biofuel feedstock production is lack of knowledge regarding crop establishment techniques. Roadside or NTAL areas are generally not managed as typical agronomic areas would be. Roadsides, for example, are a disturbed environment and designed to serve a singular purpose. Because of this situation, compaction in arid soils along roadsides has been discovered as one of the prohibiting factors in growing biofuel feedstocks along roadsides in Utah. For example, compaction along roadsides prohibited the closing of the furrow over the seed as depicted in Figure 3.1.

Figure 3.1. Illustration of post planting open furrow conditions.

A new paradigm regarding the construction and use of these areas needs to be considered in light of their abundance and potential. The conditions along roadsides
must be examined through an agronomic perspective in order to evaluate their use for biofuel feedstock production. It is the purpose of this study to investigate the planting, growing, and harvesting methods to rapidly adopt, financially grow, and convert oil seed crops on non-traditional cropland into renewable, clean burning biofuels.

Materials and Methods

Roadside Plot Locations

NTAL plots were established on four freeway rights of ways in Utah during 2007 in a collaborative project between the Utah Department of Transportation and Utah State University. Roadside plots were planted on sloping areas of highway shoulders in four Utah regions along the I-15 UDOT corridor. The four locations included plots on the south bound on ramp at exit 385 near Tremonton Utah (Tremonton), on the south bound turnout near Kaysville Utah (Kaysville), mile marker 240 (MM240) of I-15 south of Santaquin Utah and the east side of the freeway near the Mona Utah Exit (Mona). The Mona site was abandoned after 2007 trials due to inadequate topsoil conditions.

A control location exhibiting traditional agronomic conditions was established at the USU Kaysville Experiment Station. This site was established to compare normal agronomic practices and served as a control measure to compare with highway conditions.

Roadside Climatic Conditions

Climatic conditions in test areas were measured utilizing weather data from the Western Regional Climate Center (2010).
Roadside Soil Conditions

Soil Nutrient. Soil depth, along with samples for nutrient, pH, EC, and OM were taken with a standard soil probe made from chrome molybdenum type 4130 steel with a hardened tip and nickel plated for rust resistance. The probe was inserted into the soil approximately 6 inches in depth and the resultant core was placed in a bucket. It was mixed with three other core samples. A subsample of this composite was taken for analysis.

Soil Analysis Methodology. The following soil analysis methods were used:

- Soil pH and EC - 1:2 soil:water extract Method
- OM – Total Kjeldahl Nitrogen (TKN) Method
- N - KCl Extraction/Cd-Reduction Method
- P, K - Sodium Bicarbonate Method
- Zn, Cu, Fe Mg - DTPA Extraction Method
- S - Calcium Phosphate - Turbidimetric Method

References for each method listed above may be found at http://cropandsoil.oregonstate.edu/wera103/soil_methods.

Bulk Density. Soil samples for bulk density were taken with a 2 inch, inner diameter, by 6 inch length, steel AMS Soil Core Sampler with Slide Hammer. The AMS Slide Hammer has a mass of about 10 pounds and attached directly to the sampler Top Cap. The core Sampler was inserted into the ground to 6 inch depths and resultant soil collected. Soil was weighed in its moist state and then put into a drying oven at 105º F for 24 hours. Dry soil was weighed and the bulk density was calculated via the following equation:
Bulk density = dry weight (grams) ÷ volume (cm³)

Where dry weight is oven dried weight of soil sample and volume was 250 cm³ for 2” × 6” core sampler cylinder.

Cone Penetrometer

Cone penetrometer readings were taken in each plot with the Field Scout® Soil Compaction Meter to measure compaction. The penetrometer, equipped with an ASAE standard cone, was inserted into the ground. The resistance of the cone as it is pushed in the ground was measured and recorded in the memory of the compaction meter. The depth of the cone below soil surface was also measured and recorded in the memory. Compaction data were recorded and displayed at one inch intervals, in PSI. Cone penetrometer estimate data was compared to bulk density measurements.

Results and Discussion

Roadside Climatic Conditions

The spring and summer of 2007 presented one of the hottest and driest periods in Utah history. Coupled with later April and May plantings, this led to a harsh growing environment for roadside conditions. Figures 3.2-3.6 illustrate the lack of precipitation during the 2007-2008 growing season for each of the sites. The sites included Tremonton, Mona, and Farmington.
Figure 3.2. Roadside plot area precipitation data 2007.

Figure 3.3. Roadside plot area precipitation data 2008.
Figure 3.4. Roadside plot area precipitation data 2007.

Figure 3.5. Roadside plot area precipitation data 2007.
Lack of moisture made growing conditions difficult during the summers of 2007-2008 and was a factor in low crop yields. This is reflected by the low yields observed under normal agronomic conditions as well. Soil fertility was similar, if not actually improved, in traditional agronomic control plots when compared to the roadside plots. Consequently, soil fertility was ruled out as a cause for reduced yield.

**Roadside Soil Conditions**

Figure 3.7 represents a cross section of a typical road construction. Of particular interest is the shoulder portion of the diagram that illustrates the increasing depths of topsoil the further away from pavement. As distance increases from the edge of pavement, so does depth of topsoil.
Figure 3.2. Cross section of typical road constructions.
Roadside soil conditions were agronomically acceptable with the exception of compaction. Textures ranged from loam to sandy loam, but were similar along the Utah I-15 corridor. This could be explained by UDOT landscaping specification issues for topsoil when roadsides are constructed.

Soil nutrient content for the different plot locations along the I-15 corridor was variable (Figure 3.7). Figure 3.8 shows that the salt content, organic matter (OM) and pH were within normal ranges of western calcareous soils. These results were unexpected due to the high level of salts used on roads for ice melting operations during the winter. Investigators expected the salt and pH levels to be high, but this was not observed in any of the locations. However, soil compaction levels measured on the roadsides were higher than expected.

![Soil Nutrient Content - Freeways to Fuel 2007](image)

**Figure 3.3.** Specific nutrient content of roadside soils.
Figure 3.4. Organic matter, pH, and electrical conductivity of roadside soils.

Figure 3.10 shows that roadside conditions were similar between the nutrient analysis of roadside and farm control conditions. Control conditions were taken from a plot site located at the USU Kaysville Research Farm. The control plot site was tilled in 2007 with a “duck foot” ripper, and the seed bed was prepared with a roller harrow prior to samples being taken or plots being established.

Compaction numbers were the most surprising element in the soils analysis of roadside plots. Utah has freeze thaw cycles, and investigators anticipated that this would affect the compaction status of the roadside soils over the lifetime of the road. Bulk density and cone penetrometer compaction readings were taken throughout roadside plots. Both measurements showed that soil compaction levels were well above normal growing conditions. Wolkowiski and Lowery (2008) have reported on the effects of levels of bulk densities above 1.3 g/cm³ on yields. They report that compaction affects nutrient availability and uptake, proper air and water dynamics, plant emergence and growth, in
the soil. These limitations have deleterious effects on crop development and yields (Wolkowski & Lowery, 2008). Figure 3.5 shows that average soil bulk density ($\rho$) under roadside conditions averaged $\geq 0.98$ oz/in$^3$ (1.7 g/cm$^3$). These results would adversely affect agronomic growth of oilseed crops by limiting air, water, and microbial activity to plants.

![Roadside Soil Quality - F2F 2007](image)

**Figure 3.5.** Average soil conditions along roadsides vs. control.

Roadside compaction was further investigated utilizing a cone penetrometer as reported in Figures 3.11, 3.12, and 3.13. The cone penetrometer data confirms the difference in compaction along roadsides relative to acceptable levels.
Figure 3.6. Bulk density measurements of roadside soil conditions vs. control (traditional agronomic conditions).

Figure 3.7. Cone penetrometer readings for plot roadside soils vs. control (traditional agronomic conditions).
Soils near roadsides, airports, railways, and military installations are in highly disturbed areas that have been engineered for anthropogenic uses. They are non-native environments and are often a safe harbor for pests. The NTAL model provides several environments such as, wildlife areas, native habitat areas, open space, and green zones—this can be considered a biofuel feedstock mosaic. The biofuel feedstock mosaic suggests multi-use of the area with several different functions.

In these areas it was observed that established/native plant species were being displaced by aggressive weedy species such as *Bromus tectorum* (downy brome).
Production of biofuel crops in the NTAL model may be a strategy to decrease the weed seed pressures and allow for re-establishment of desirable native species.

With the exception of this dissertation, few scientists have focused on the production of biofuel feedstock crops along roadsides. In developing the NTAL model, consideration was given to other professionals already working on these areas. One of the most progressive groups in managing roadside vegetation is the National Roadside Vegetation Management Association, which is a Federal Highway Administration division of maintenance engineers, ecologists, and plant scientists.

For this project, a cursory inventory of vegetation was taken before and after the establishment of plots via visual evaluation. This visual evaluation showed alfalfa, bunch grasses (such as perennial tall wheatgrass), sweet clovers and weedy species such as *Sisymbrium altissimum* (tumble mustard), *Isatis tinctoria* (dyers woad) and downy brome. Vegetation along roadways in Utah is well established but is generally not native. Often seeded species are hybrids and are established as part of a hydroseeding mix that contains other plant species such as *Melilotus spp* (sweet clover), *Medicago sativa* (alfalfa), and *Linum usitatissimum* (flax). The most prevalent vegetation observed along the roadsides was *Agropyron cristatum* (crested wheat grass).

It was hypothesized that vegetation shifts might occur if roadside areas are utilized for biofuel crop production. A vegetative shift in the flora was observed within one year of establishment of roadside biofuel crop plots. When established perennial grasses were removed, through glyphosate application, different species of opportunistic vegetation began to dominate the plots. Species that invaded the open plots included tumble mustard, field bindweed and downy brome.
Species shifts in the roadside environment are a common occurrence for departments of transportation (DOT). DOT’s dedicate a sizeable annual budget to weed control—often noxious weeds—in these areas. One of the objectives of the NTAL model is to control weeds while producing a renewable, sustainable fuel. Roadside areas will always be disturbed sites, with disturbed soils, because of their function as transportation corridors. It is proposed that the NTAL model be used as a technique to develop a mutualistic relationship that would decrease the carbon footprint of maintenance and increase sustainability by producing a lower emission, renewable energy.

It is biologically unsound to assume that an oilseed crop can be produced on a continual basis without the introduction of a rotational crop. Types of rotational crops could include native plants grown for seed production. As biomass refining technology improves, roadside areas could be used to grow feedstocks for biological/thermal energy conversion platforms. During the course of this study, there has been interest in utilizing roadside areas for algae production for biofuel feedstock (cellulosic ethanol, torrefaction, pyrolysis, gasification). These technologies are in development, but the first iteration of the NTAL model would rotate oilseed crops with grass seed crops and then follow the technology developments of energy production. Native plants could be utilized for both biomass and ecological activities, but their natural cycle would be disrupted by the operations of harvesting.

In roadside areas, DOT’s are trying to discourage wildlife activities for public safety reasons such as auto/wildlife encounters. DOT’s have limits on the height, type, and quality of biomass that can be considered for roadside projects. For example, Tennessee, Massachusetts, and other states are considering growing a native prairie
grass along roadways for biofuel production. However, the grass will not be able to mature to its maximum yield because its height would be too great and create line of sight hazards.

Measurement of existing biomass along plot areas was pursued, but access to this biomass was not permitted by UDOT because it was not within the scope of the current project. It would be of great interest to know the value of the biomass currently growing along roadsides in Utah to compare with oilseed crop production.

**Conclusion**

Agronomic conditions along Utah’s roadways are conducive to crop growth with the exception of soil compaction. Utah precipitation and climate appear to be major factors in determining whether the NTAL model will be financially and agronomically successful. Data showed that there is no evidence of elevated salt levels in roadside soils. Soil texture, organic matter, pH, and nutrient contents are acceptable for the growth and development of oilseed feedstock crops such as canola and safflower.

This research shows roadsides are disturbed ecosystems usually designed for anthropogenic uses. Utah roadsides have varying soil conditions and depths as one moves away from the edge of the payment. Generally topsoil depth increases the farther away from the edge of the pavement. These varying conditions may be conducive to different types of roadside usage including biofuel feedstock growth. Other elements of roadside use may include conditions that satisfy open/green space corridors, native vegetation and erosion/drainage systems.

Care must be taken in consideration of roadside conditions to not affect the structural component of the roadsides. Roadside areas are usually engineered for a
specific purpose and typical agronomic activities would disturb this. Conventional tillage for seedbed preparation, weed control and residue eradication near roadsides threaten the engineered purpose of these areas.
CHAPTER 4
ROADSIDE PLOTS

Introduction

The NTAL project can serve as a model for crop establishment for all regions of the United States and needs to be explored in situ (e.g. roadsides, airports, military installations) so that yield and environmental impacts such as soil quality, water quality, wildlife encroachment, structural integrity, local grower concerns, and safety are considered. Proper crop selection and establishment correlates to regional conditions essential to the success of this program.

It was the goal of this dissertation to develop sustainable, agronomic crop growth methods that will allow feasible oilseed feedstock production in marginal or non-traditional agronomic areas (e.g. roadways, railroads, airports, military installations). It was proposed that non-traditional feedstock production for oilseed crops would be evaluated and a process for crop production would be developed in a 3- to 4-year period. It was anticipated that project partners with successful production will remain as long-term biofuel feedstock sources in their respective regions of the United States. If successful, this process would generate four positive outcomes:

- Produce sustainable fuels from idle areas that are costly to maintain.
- Provide a mechanism to decreased cost of controlling weeds harbored by these areas.
- Provide support to the local economy by providing jobs/renewable energy.
• Provide a template/screening process for all related lands that could be used for biofuel production after the current process has been demonstrated successful.

The focus for NTAL will be an evaluation of the agronomic conditions and growth requirements for biodiesel and other biomass feedstock crops.

Biodiesel is a renewable, high energy input/output ratio (1:4.56) fuel with technology that is currently in use, is financially viable, has an established distribution chain, and has proven processing methods with no waiting or promises of technology “to be developed” in the future (Pradhan, Shrestha, Van Gerpen, & Duffield, 2008). The feedstocks produced from the NTAL model will be readily turned into biodiesel which can be used immediately in the fuel supply chain. The fluctuating costs of petroleum suggest that the use of non-traditional agronomic resources for biofuel production is timely.

In the consideration of the NTAL project a multitude of unknowns were identified. Questions regarding biofuel feedstock production on non-traditional crop land that were unanswered are:

• Will the varied soil conditions along roadsides support financially feasible crop yields?
• Will conventional farming equipment satisfy the cropping requirements for oilseed crop production in the roadside setting?
• Will the disturbance of planting and the elimination of current plant populations in these areas change erosion patterns?

Based upon these questions, a research protocol was developed to address the unknowns identified.
Materials and Methods

2007 Test

Plots for Non-Traditional Agronomic Land were established on freeway rights-of-way shoulders in Utah during 2007 under the direction of the Utah Department of Transportation. Experimental design for the roadside plots was a completely randomized block design consisting of four treatments replicated in each of four blocks. The blocks were planted on sloping areas of highway shoulders in five Utah regions along the I-15 UDOT corridor. These locations were near Tremonton, Kaysville, Mona (two locations), and St. George, Utah. A control location at the Utah State University Kaysville Research Farm was established to compare normal agronomic practices and serve as a control measure to highway conditions. All locations were planted with safflower, spring canola (Roundup Ready), and winter canola (Roundup Ready). The treatments at each location are shown in Table 4.1.

Table 4.4
NTAL Roadside Plot Treatments

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Variety</th>
<th>Seeding Rate</th>
<th>Glyphosate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>spring canola</td>
<td>Hyola 357</td>
<td>7 lbs/A)</td>
<td>no</td>
</tr>
<tr>
<td>spring canola</td>
<td>Hyola 357</td>
<td>7 lbs/acre</td>
<td>yes</td>
</tr>
<tr>
<td>fall canola</td>
<td>DKW 1386</td>
<td>7 lbs/acre</td>
<td>yes</td>
</tr>
<tr>
<td>fall canola</td>
<td>DKW 1386</td>
<td>7 lbs/acre</td>
<td>no</td>
</tr>
<tr>
<td>Safflower</td>
<td>S-208</td>
<td>15 lbs/acre</td>
<td>no</td>
</tr>
</tbody>
</table>
The distribution of plot locations allowed for different climatic exposure and public interaction. Plot sizes were 8’ X 45’ and served as areas for two crop years. Each plot was divided into two sections. The first 20’ of each plot was sprayed with glyphosate based herbicide Roundup Weathermax (30 oz/acre) in preparation for planting. The remaining 25’ portion was utilized the following season for a second evaluation of each treatment. 5’ was used as a buffer and 20’ was used as plot area in year 2. Varieties planted at both roadside and the control plots included safflower (S-208) and glyphosate tolerant canola (Hyola 357). The roadside plots were planted using a Tye Pasture Pleaser no-till drill equipped with ¾” depth bands.

**2008 Test**

The experimental design for the 2008 roadside plots was a completely randomized block design with four treatments replicated in each of four blocks planted on sloping areas of highway shoulders in four Utah regions along the I-15 UDOT corridor. These locations were near Tremonton, Kaysville, and mile marker 240 near Mona, Utah. In 2008, only four roadside sites were utilized compared to 5 in 2007. One of the two Mona sites was eliminated because the soil at the sites contained excessive amounts of aggregate. The 2007 St. George site was removed from the 2008 experimental test because of road construction in the test area. The treatments at each location were identical to 2007 treatments above (Table 4.1).
Table 4.5

*Planting Information for Roadside Plots*

<table>
<thead>
<tr>
<th></th>
<th>Location</th>
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<tbody>
<tr>
<td></td>
<td>Tremonton</td>
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<td>MM240</td>
<td>St. George</td>
<td>Control</td>
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</tr>
<tr>
<td><strong>Spring Planting Information</strong></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planting Date</td>
<td>5/1</td>
<td>4/3</td>
<td>5/8</td>
<td>4/3</td>
<td>5/1</td>
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<td>11/8</td>
</tr>
<tr>
<td>Planting Depth (inches)</td>
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<td>2</td>
<td>0.75</td>
<td>2</td>
<td>0.75</td>
</tr>
<tr>
<td>Spring Canola Planting Rate (lbs/acre)</td>
<td>5 6</td>
<td>5 6</td>
<td>5 6</td>
<td>5 6</td>
<td>5 6</td>
<td>5 6</td>
<td>5 6</td>
</tr>
<tr>
<td>Safflower (lb/acre)</td>
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<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td><strong>Fall Planting Information</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planting Date</td>
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<td>9/25</td>
<td>10/4</td>
<td>9/25</td>
<td>10/4</td>
<td>9/25</td>
<td>11/8</td>
</tr>
<tr>
<td>Planting Depth (inches)</td>
<td>0.75</td>
<td>2</td>
<td>0.75</td>
<td>2</td>
<td>0.75</td>
<td>2</td>
<td>0.75</td>
</tr>
<tr>
<td>Fall Canola (lbs/acre)</td>
<td>5 6</td>
<td>5 6</td>
<td>5 6</td>
<td>5 6</td>
<td>5 6</td>
<td>5 6</td>
<td>5 6</td>
</tr>
</tbody>
</table>

**Results and Discussion**

The 2007 spring canola plants emerged in three locations. Although emergence occurred in Kaysville and Tremonton plots, plant populations were low when compared to control plots (Figure 4.1). Emergence at both Mona sites was not measurable.

Establishment of canola and safflower was determined by counting the plants when they were at the 2-6 leaf stage of development.
Figure 4.9. Relative canola emergence populations.

The 2007 safflower plants emerged in four locations, Kaysville, MM240, Mona, and Tremonton. All plant populations were low when compared to control plots at the Kaysville Research Farm (Figure 4.2).

In 2008 neither canola nor safflower plants emerged after seeding. Lack of emergence made it impossible to report growth data and thus no establishment data are available for the 2008 crop year at any location.

Figure 4.3 shows the summary of yields from Non-Traditional Agronomic Land crops grown along roadsides in Utah. The difference between 2007 and 2008 was the
depth of planting. In 2008, the depth bands were removed from the planting equipment to permit deeper seed placement in the soil to access moisture and decrease the influence of compaction. Although seeds were placed at a greater depth to enhance germination and emergence, no plants were established. Control plots were seeded with depth bands removed and crop establishment did not occur. Under optimal conditions or roadside conditions, no plant emergence occurred. Over both years, yields were less than acceptable in terms of financial feasibility. In 2007, unusual climatic conditions (figures in Chapter 3) reduced production to a yield of 700 lbs/acre. In 2008, no safflower yield was observed. This may have been due to deeper planting depths, climatic and agronomic conditions or a combination.
The extreme compaction reported in Chapter 3 also affected the planting of the oilseed crops along the roadsides. The Tye Pasture Pleaser Drill was able to penetrate the compacted soils, but the press wheel was unable to seal the furrow that was created. This left the seed without seed cover and germination/establishment did not occur.

**Conclusion**

After evaluation and analysis of these data, it was possible to conclude that spring canola and safflower production along UDOT rights-of-way was not profitable under reported conditions and methodology for 2007 and 2008. The no-till methods used were able to penetrate the soil substrate, but unable to successfully close the seed
furrow it created. Subsequently, the seed was left with minimal soil over and failed to produce financial yields. In those instances where seed-to-soil contact produced a seedling, it did not support a productive plant.

Field data, combined with greenhouse data (see chapter 5), made it possible to conclude that soil compaction and seeding depth had the most significant effect on safflower establishment, growth and development. While initial research did not produce favorable yields, it did establish a baseline from which further hypothesis could be constructed. The knowledge gained from this introductory work may allow agronomists to work with roadside engineers to develop new techniques and paradigms for alternative uses of roadsides.
CHAPTER 5
GREENHOUSE

Introduction

A micro phase of NTAL research took place in the USU greenhouses. In this phase of research the objective was to evaluate issues related to low crop emergence/establishment and reduced yields in the roadside plots during the 2007/2008 growing seasons. Issues considered during this research were the effects of soil moisture, compaction, planting methods and effects on emergence of safflower in roadside plot conditions. The goal was to simulate roadside conditions during the 2007/2008 growing season and explore the causes and possible solutions to compaction and drought that decreased crop growth and development. It was hypothesized that this activity would help further explain some of the effects of roadside conditions and climate on crop production.

Materials and Methods

Experiments were conducted in 10 inch X 2.5 inch rigid plastic containers filled with road base in the lower half and topsoil from Kaysville roadside plot areas on top. Both materials were compacted to desired bulk density during filling of the container. Seeds were planted at 0", 0.39", 0.79", 1.81", 1.57", 1.97" inch (0, 1, 2, 3, 4, and 5 cm respectively) in the soil portion of the container to determine optimum planting depth under roadside conditions using various planting techniques.
Each depth was replicated four times to ensure confidence and statistical significance and the experiment was repeated 2X. Seeds were placed into two soil moisture regimes. One set of treatments was grown in soils that were brought to field capacity before planting and another set was grown under drought conditions similar to those exhibited in 2007–2008. Successful establishment was measured by plant seedling dry weight biomass.

**Volume of Conetainer**

The volume of the 10” conetainer was measured by taping the bottom openings and filling with water at \( \approx 41^\circ F \) (5°C). The volume of the water was weighed. This was repeated four times and weights were averaged. The resultant weight of the water in the conetainer was 20.46 oz ((580 gm) assume 1 cm\(^3\) of water = 1 gm of water). Volume of the cone was 20.46 oz (580 cm\(^3\)) = 19.61 fl oz. Bulk Density was calculated by the following:

- Volume of conetainer = 19.61 fl oz (580 cm\(^3\)). Desired bulk density of soil in conetainer = 0.98 oz/in\(^3\) (1.7 gm/cm\(^3\)). 19.61 fl oz (580 cm\(^3\)) x 0.98 oz/in\(^3\) (1.7 gm/cm\(^3\)) = 35.80 oz (1015 gm).

- Calculating bulk density for \( \frac{1}{2} \) conetainer volume = desired bulk density = 0.98 oz/in\(^3\) (1.7 gm/cm\(^3\)) x 0.5 x 35.80 oz (1015 gm) = 17.92 oz (508 gm) per \( \frac{1}{2} \) of conetainer.

Determining the level of soil corresponding to appropriate bulk density in the conetainer was considered. Half volume of the conetainer was determined volumetrically and marked on the exterior of the conetainer.
Filling the Container

Pre-weighed road base was placed into containers and compacted to the correct level by dropping a 2.0 inch (5.08 cm) × 5.0 inch (12.7 cm) piece of steel rod with a total weight of 1095 gm.

An adjustment for Soil and Road Base moisture content was determined according to the following steps:

1. \[ 17.70 \text{ in}^3 (290 \text{ cm}^3) = \frac{1}{2} \text{ volume of the container} \]
2. Roadbase ((\(\frac{3}{4}\) minus which is aggregate material that will pass a 0.75 in (1.90 cm) screen))
3. Wet weight of roadbase = 12.10 oz (343 gm)
4. Dry weight of roadbase = 11.92 oz (338 gm)
5. \[ 12.10 \text{ oz} (343 \text{ gm}) - 11.92 \text{ oz} (338 \text{ gm}) \div 11.92 \text{ oz} (338 \text{ gm}) \approx 1.5\% \text{ moisture} \]
6. Correct for moisture = 17.88 oz (507 gm) of material \times 9.81 \text{ fl oz (290 cm}^3)\text{) of container} \]
7. Soil at \(9.8 \times 10^{-4}\) oz/in\(^3\) (1.7 gm/cm\(^3\))
8. Wet = 10.02 oz (84 gm)
9. Dry = 9.92 oz (253 gm)
10. \[ 10.02 \text{ oz} (284 \text{ gm}) - 9.92 \text{ oz} (253 \text{ gm}) \div 13.51 \text{ oz} (338 \text{ gm}) \approx 11\% \text{ moisture} \]
11. Correct for moisture = 17.92 oz (508 gm) \times 1.11 = 19.89 oz (564 gm) of soil per 9.81 fl oz (290 cm\(^3\)) of container
12. Soil at agronomic compaction 0.75 oz/in\(^3\) (1.3 gm/cm\(^3\)) bulk density
13. 9.81 fl oz (290 gm/cm\(^3\)) per \(\frac{1}{2}\) of container
14. 9.81 fl oz (290 cm\(^3\)) \times 0.75 oz/in\(^3\) (1.3 gm/cm\(^3\)) = 13.30 oz (377 gm)
15. Adjust for initial soil moisture @ 11%
16. 13.30 oz (377 gm) \times 1.11 = 14.74 oz(418 gm) will allow bulk density of (1.3 gm/cm\(^3\)) in the container
The topsoil was placed in the container on top of the roadbase. The container bottom openings had previously been sealed to eliminate leakage of materials. During the filling and to establish proper bulk density, the container was placed inside a concrete mold. Initial container filling to the required bulk density ruptured the sides of the container vessel because of the stress on the plastic. Therefore, a mold was constructed in a 12” greenhouse pot that had been filled with a wet concrete mixture around an empty container. After the concrete had cured, the empty container was removed. Individual containers were placed in the mold, filled, and compacted to desired bulk density.

Following the placement of the roadbase, pre-weighed topsoil was placed into the container. Topsoil was added in multiple steps to obtain the required bulk density. If all pre-weighed topsoil was placed in the container at once, the volume of the soil exceeded the capacity of the container. Approximately one third of the topsoil was placed into the container and compacted. This step was repeated 3X until the topsoil was at the correct level and properly compacted. The final level of the soil in the container was standardized to be \( \approx 0.2" \) (0.5 cm) below the lip of the container by pressing a 3" (7.62 cm) \( \times \) 2.5" (6.35 cm) plastic rod into the top of the container.

Moisture standardization of the material in the container was carried out by soaking the containers in a water filled tub until complete soil saturation had taken place. Holes were made in the seals around the bottom of the containers and gravitational water was allowed to drain for 24 hours. Moisture level in the combined roadbase and topsoil stabilized at field capacity.

Seeds were placed into the containers. A variety of tools were prototyped for simulation of planting actions that took place in the plot trials including coulter, planting
disk furrow, and press wheel effects. These were designed to simulate the Tye Pasture Pleaser No-till Drill effects on soil conditions. Hereafter in the document these are referred to as drill effects and no-drill effects.

Coulter effects of the Tye Pasture Pleasure No-till Drill were simulated using a 0.25" (0.635 cm) metal blade that had been beveled on the insertion end. The coulter simulation device was attached to a handle so that it could be pushed into the container simulating the coulter prior to seeding disks. The purpose of the coulter was to open and loosen the soil prior to planting in the no-till operation.

Planting discs from the Tye Pasture Pleaser and resultant furrow were simulated by using a hatchet type device. This furrowing tool was created with a six degree angle opening at the top narrowing to the bottom of the tool. The sharp end was inserted into the soil first.

**Planting Techniques**

Compaction vs. non-Compaction + depth treatments were simulated using a beveled, 1" (2.54 cm) diameter soil coring tool. The tool was inserted into the top of the container and soil from the appropriate depth was extracted. Two safflower seeds were placed at prescribed depth left by the removal of the soil core. The soil was replaced and then compacted to treatment specification with the plastic rod previously described.

Furrow + compaction + depth treatments were seeded by placing the furrowing tool into a prepared container to the appropriate depth, and two safflower seeds were placed at the bottom of the furrow.

Compaction + depth + furrow + coulter treatments were performed by compacting materials to specification, placing the coulter tool to a depth of 6 cm for all
Coulter treatments followed by the furrow tool to prescribed depth and two safflower seeds were placed in the bottom of the furrow.

Compaction + depth + furrow + coulter + press wheel were performed by placing the coulter tool into a prepared container followed by the furrowing tool, and placing two safflower seeds in the bottom of the furrow. The container was recompressed using the plastic rod tools as described above to simulate the press wheel effects.

**Results and Discussion**

The goal with the greenhouse project was to simulate roadside conditions and explore the causes and possible solutions that have made it so difficult to establish a crop on the roadside. Data from this experiment were collected over the summer of 2009 and has been analyzed as a linear mixed model. These data confirmed our hypothesis that depth of seed placement and compaction do affect the plant biomass production.

Figure 5.1 shows the significant effects of compaction coupled with depth of seeding influences. None of the depth values are different (p = .05) from each other as illustrated by the error bars in 5.1.

Figure 5.2 shows the significance of no compaction coupled with depth of seeding influences on biomass production. In evaluating this data: hand placing seed at the 1 cm (0.39”) depth produced highest biomass yields. The 1 cm (0.39”) depth of seed placement without compaction treatment was significantly higher (p = .05) than all other treatments. No Compaction + depth + furrow + coulter + press wheel at the 2 cm (0.79”) depth was the same as all other treatments at the equal depth. From this data, compaction was obviously the overriding factor.
Figure 5.12. Compaction data.

Where Compaction = effects of Compaction, CompactionFurrow = effects of compaction and furrow effect, CompFurrowCoulter = effects of compaction, furrow and coulter, CompFurrCltrPress = effects of compaction, furrow, coulter and press wheel.
Figure 5.13. No Compaction data.

Where No Compaction = effects of No Compaction, No CompactionFurrow = effects of no compaction and no furrow effect, No CompFurrowCoulter = effects of no compaction, no furrow and no coulter, No CompFurrCltrPress = effects of no compaction, no furrow, no coulter and no press wheel.
Figure 5.14. Combination data.

Where Compaction = effects of Compaction, CompactionFurrow = effects of compaction and furrow effect, CompFurrowCoulter = effects of compaction, furrow and coulter, CompFurrCltrPress = effects of compaction, furrow, coulter and press wheel, No Compaction = effects of No Compaction, No CompactionFurrow = effects of no compaction and no furrow effect, No CompFurrowCoulter = effects of no compaction, no furrow and no coulter, No CompFurrCltrPress = effects of no compaction, no furrow, no coulter and no press wheel.
Figure 5.3 consolidates the response of depth of seeding and compaction. Fig 5.3 also shows differences between combination of coulter, furrow and press wheel (simulated no-till drill effects) and non-drill effects compaction vs. non compaction since the treatment x depth interaction is significant, treatment effects were examined at each depth level. The results indicate that the treatments have only significant effects on log biomass at depth 0.39 in (1 cm) and 0.79 in (2 cm) at alpha=0.05. Results are listed in attached spreadsheet ‘slices.’

From the Figures 5.1, 5.2, and 5.3 listed above, it was hypothesized that (1) non-compacted soils produce more biomass; and (2) seeds planted at shallow depths at 0.39 in (1 cm) and 0.79 in (2 cm) produced more biomass than other depths. The hypotheses were tested using ESTIMATE in PROC MIXED. Results are listed in the spreadsheet ‘estimates’. Note that depth 2 & 3 in the table represent depths level 2 and 3, which are 0.39 in (1 cm) and 0.79 in (2 cm), respectively. The analysis results showed that (1) soils without compaction produce more biomass than soils treated with compaction; and (2) seeds planted at 0.39 in (1 cm) and 0.79 in (2 cm) produce more biomass than those planted at other depths. All conclusion were made at alpha=0.05.

Pairwise comparisons of each treatment pair are found in attached spreadsheet Appendix E. Note that only significantly different treatment pairs were listed.

Testing the null hypothesis that none of the treatment factors have an effect on biomass yield, produced a p-value of less than .0001, which implies we can reject this null hypothesis and conclude that at least one of the factors has a significant effect on the yield.

Depth and Compaction are significant in their effect on the yield between their different levels. These data suggest that no compaction produces a slightly higher yield
than using compaction. Mean yield for no compaction was 0.037 gm, and using compaction produced a mean yield of 0.018 gm.

For Depth, these data showed that planting at a depth of 0.39 in (1 cm) and 0.79 in (2 cm) is better than planting at 0 in or > 0.79 in (2 cm) depths. This shows that the mean yield decreases as planting depth increases.

The highest mean yield of $0.1.85 \times 10^{-3}$ oz was with no compaction and a 0.79 inches (2 cm) depth. Treatment (compaction vs. non-compaction), seeding depth and their interaction are all significant. Results are listed in Table 5.1.

Table 5.6
Type 3 Fixed Effects

<table>
<thead>
<tr>
<th>Effect</th>
<th>NumDF</th>
<th>DenDF</th>
<th>FValue</th>
<th>ProbF</th>
</tr>
</thead>
<tbody>
<tr>
<td>treatment</td>
<td>7</td>
<td>335</td>
<td>6.350796</td>
<td>0.0000005</td>
</tr>
<tr>
<td>depth_cm</td>
<td>5</td>
<td>335</td>
<td>13.19368</td>
<td>0.0000000</td>
</tr>
<tr>
<td>treatment*depth_cm</td>
<td>35</td>
<td>335</td>
<td>1.506019</td>
<td>0.037003</td>
</tr>
</tbody>
</table>

**Conclusion**

The depth of the seed and compaction of soil had significant effects on biomass produced. This supports our initial hypothesis that a limiting factor of the roadside plots was compaction. This experiment confirms that the depth of seed placement and the
level of soil compaction is critical to plant establishment and growth in NTAL conditions.

From the experiment results discussed, we recommend that safflower grown under these conditions be placed at a seeding depth of 1 – 2 centimeters.
CHAPTER 6
ROADSIDE SIMULATION

Introduction

To more closely control experiments and evaluate alternative agronomic practices restricted by UDOT, a Roadside Simulation Laboratory (RLS) was constructed at the Utah State University Utah Botanical Center (UBC). The RLS was essentially the “laboratory” portion of the NTAL design to more closely examine combined methods of planting and fertilization. In addition, the RLS permitted research into planting methods, germination rates and crop establishment in a roadside environment.

The experimental activities for the simulated roadside laboratory plot explored alternative planting methods to relieve compaction and improve growth conditions. One of the research questions related to the NTAL project involved utilization of composted material for crop fertility. Parties engaged in this discussion included local waste water treatment managers, crop and soil scientists, and UDOT regarding application of composted material from waste water treatment operations. It was anticipated that use of composted materials would increase yield and decrease erosion events in oilseed production. From resultant discussions, the following research questions were formulated:

1. Can the banding of composted material over the seeded row improve seed emergence and crop yield?
2. Will aeration of soil be effective in relieving compaction prior to planting?
3. Will the combination of compost and aeration be more effective at crop production than either alone?
Based on these questions, the following hypothesis was developed: If soil were aerated prior to planting and then compost was applied over seedbeds during planting to improve soil quality, nutrient content, water retention, germination, and decrease crusting and erosion—all in one pass—then yields would increase.

**Materials and Methods**

The RSL was established in 2008. It consisted of a compacted 6-inch layer of $\frac{3}{4}$ inch minus road base covered by a 6-inch layer of compacted topsoil. Bulk densities of the topsoil on the RSL were compacted to bulk density of 1.12 oz/in$^3$ (1.94 g/cm$^3$).

Figure 6.1 is a cross section cut of the RSL illustrating stratified layers of different materials used to build the RSL. The top 6-inch of soil is clearly visible when contrasted against the lighter 6-inch layer of roadbase below.

The experimental design for the RSL was a complete split plot randomized block design with 4 split plot treatments replicated in each of the three blocks. Safflower (variety S-208) was planted at a rate of 15 lbs/acre in the various treatments. The treatments for the simulated roadside laboratory are shown in Table 6.1.

Other crops researched under RSL conditions were spring and winter canola, winter safflower and camelina (Camelina sativa). Planting of the plots was conducted with a New Holland tractor, an Aerway Aerator, and a Tye Pasture Pleaser No-Till Drill on respective treatments.
Table 6.7
*RSL Plot Treatments*

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Composta</th>
<th>Aeration (Aerway Offset)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control/No-till</td>
<td>No</td>
<td>0°</td>
</tr>
<tr>
<td>Biosolids Banding/No-till</td>
<td>5 tons/acre</td>
<td>0°</td>
</tr>
<tr>
<td>Aerway/No-till (culti-planting)</td>
<td>no</td>
<td>0°</td>
</tr>
<tr>
<td>Aerway/No-till/Biosolids Banding (cubanding)</td>
<td>5 tons/acre</td>
<td>0°</td>
</tr>
<tr>
<td>Control/No-till</td>
<td>no</td>
<td>15°</td>
</tr>
<tr>
<td>Biosolids Banding/No-till</td>
<td>5 tons/acre</td>
<td>15°</td>
</tr>
<tr>
<td>Aerway/No-till (culti-planting)</td>
<td>no</td>
<td>15°</td>
</tr>
<tr>
<td>Aerway/No-till/Biosolids Banding (cubanding)</td>
<td>5 tons/acre</td>
<td>15°</td>
</tr>
</tbody>
</table>

*a5 tons/acre equivalent compost was banded by hand over the tops of the respective treatments post planting*

Plots were harvested using an Almaco Research Combine with a 4 ft wide head. Split plots were harvested in their respective treatment keeping the header between the middle open row spaces separating the treatments.

In order to monitor safflower seed loss and combine efficiency, one row of safflower per plot in replication three was hand harvested and compared to the yields of the rest of the representative plot. Table 6.2 shows data comparing the combine efficiency to hand harvest.
In order to monitor safflower seed loss and combine efficiency, one row of safflower per plot in replication three was hand harvested and compared to the yields of the rest of the representative plot. Table 6.2 shows data comparing the combine efficiency to hand harvest.

Plots were measured for soil bulk density post-harvest for compaction disturbance within each treatment. Bulk density measurements were conducted using an AMS 2” x 6” Signature SCS Soil Coring Tool.
Table 6.8

USU Almaco Research Combine Efficiency

<table>
<thead>
<tr>
<th>Plot Number</th>
<th>306</th>
<th>309</th>
<th>312</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 row harvest with combine gms</td>
<td>300</td>
<td>228</td>
<td>207</td>
</tr>
<tr>
<td>1 row harvest by hand gms</td>
<td>95</td>
<td>148</td>
<td>105</td>
</tr>
<tr>
<td>1 row adjusted to 4 rows gms</td>
<td>380</td>
<td>592</td>
<td>420</td>
</tr>
<tr>
<td>adjustment factor</td>
<td>1.3</td>
<td>2.6</td>
<td>2.0</td>
</tr>
<tr>
<td>average adjustment factor</td>
<td></td>
<td></td>
<td>2.0</td>
</tr>
</tbody>
</table>

Results and Discussion

Crops tested under RSL conditions included spring and winter canola, spring and winter safflower, and camelina. Only spring safflower (variety S208) trials produced significant enough yields to report. Spring safflower crops were harvested during the month of September 2009. Data from the 2009 harvest was collected and formatted in Figure 6.2.

Figure 6.16. Yields of 2009 roadside simulation laboratory safflower plots.
The safflower + aeration (culti-planting) technique yielded the highest amount of safflower. It was anticipated that the safflower + aeration + compost (culti-banding) treatment would be the highest yielding treatment. It is probable that the compost was not mature (C:N ratio was >20) and should have been placed on soils months before planting. This would have allowed for mineralization of the nutrients in the compost to occur providing necessary nutrients for plant growth. Compost has been reported to immobilize the nutrients during mineralization. This may have affected safflower growth because of nutrient unavailability. Immature compost can lead to nitrogen immobilization for a few months due to microbial transformations in the soil (Eghball, Wienhold, Gilley, & Eigenberg, 2002).

Bulk density measurements between disturbed RSL soils (Aerway treatment) and undisturbed soils (no Aerway treatment) remained unchanged post-harvest in 2009.

Conclusion

With the previous work and experience on NTAL’s, baselines were drawn from yield failures. It was hypothesized that soil compaction must be relieved without disturbing structural design of roadsides. New soil compaction relief equipment and the RSL was a critical addition to the project and solved several agronomic problems. With aeration techniques described in this chapter, extreme soil compaction was relieved enough to produce financially viable yields of biofuel feedstock.

The safflower + aeration treatment yielded the highest amount (583 lbs/acre) under RSL conditions. This was a milestone because this yield represented the first breakeven point financially for the NTAL method. No other treatments to date have obtained this goal under RSL or roadside conditions. In addition, newly developed culti-
planting methods showed financially viable yields while preserving compaction for roadside structure and safe travel.

Table 6.9
Financial Model of Non-Traditional Agronomic Land

<table>
<thead>
<tr>
<th>Estimated Costs and Returns - Oilseed Production/Acre on Roadsides</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Revenue/Acre</strong></td>
</tr>
<tr>
<td>$130.00 sales/acre (67% oil to biodiesel conversion)</td>
</tr>
<tr>
<td>Meal sales</td>
</tr>
<tr>
<td><strong>Total Revenue/Acre</strong></td>
</tr>
</tbody>
</table>

**Safflower Production and Processing Costs**

<table>
<thead>
<tr>
<th>Processing Costs</th>
<th><strong>Units</strong></th>
<th><strong>$/Unit</strong></th>
<th><strong>Total</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Processing costs</td>
<td>gallons</td>
<td>27.5</td>
<td>$0.50</td>
</tr>
<tr>
<td>Roasting costs</td>
<td>gallons</td>
<td>27.5</td>
<td>$0.89</td>
</tr>
<tr>
<td>Fuel tax credit</td>
<td>gallons</td>
<td>20.6</td>
<td>$1.00</td>
</tr>
<tr>
<td><strong>Total processing costs</strong></td>
<td></td>
<td></td>
<td><strong>$8.07</strong></td>
</tr>
</tbody>
</table>

**Production Operating Costs**

<table>
<thead>
<tr>
<th>Seed</th>
<th></th>
<th><strong>$/Unit</strong></th>
<th><strong>Total</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Fertility from Biosolids - NPKS</td>
<td>pounds</td>
<td>15</td>
<td>$0.35</td>
</tr>
<tr>
<td>Fertility from Fertilizer N, P, K</td>
<td>tons</td>
<td>1</td>
<td>$10.00</td>
</tr>
<tr>
<td>Herbicide - glyphosate 20 oz 41%</td>
<td>lbs</td>
<td>0.3</td>
<td>$10.00</td>
</tr>
<tr>
<td>Pesticide - other</td>
<td>lbs</td>
<td>0.1</td>
<td>$10.00</td>
</tr>
<tr>
<td>fertilizer/pesticide application</td>
<td>acre</td>
<td>1</td>
<td>$6.05</td>
</tr>
<tr>
<td>Drilling, no-till</td>
<td>acre</td>
<td>1</td>
<td>$15.95</td>
</tr>
<tr>
<td>Harvesting</td>
<td>acre</td>
<td>1</td>
<td>$27.40</td>
</tr>
<tr>
<td>Hauling to Depot (100 mile radius, 1 way, bwf 42 lbs)</td>
<td>buisacre</td>
<td>14.29</td>
<td>$0.29</td>
</tr>
<tr>
<td>Movs</td>
<td></td>
<td>1</td>
<td>$10.00</td>
</tr>
<tr>
<td><strong>Total Operating Costs/Acre</strong></td>
<td></td>
<td></td>
<td><strong>$107.82</strong></td>
</tr>
</tbody>
</table>

**Production Fixed Costs**

<table>
<thead>
<tr>
<th>General Overhead</th>
<th></th>
<th><strong>$/Unit</strong></th>
<th><strong>Total</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Management Fee</td>
<td></td>
<td></td>
<td>$5.00</td>
</tr>
<tr>
<td><strong>Total Cash Ownership Costs/Acre</strong></td>
<td></td>
<td></td>
<td><strong>$5.00</strong></td>
</tr>
</tbody>
</table>

**Total Production Cost/Acre**

<table>
<thead>
<tr>
<th><strong>Total Costs (Processing and Production)</strong></th>
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<th><strong>$/Unit</strong></th>
<th><strong>Total</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>$113.82</strong></td>
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<table>
<thead>
<tr>
<th>Fuel Production Profit/Acre</th>
<th></th>
<th><strong>$/Unit</strong></th>
<th><strong>Total</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>$10.83</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Integrated Profit/Acre**

<table>
<thead>
<tr>
<th>Integrated Profit/Acre</th>
<th></th>
<th><strong>$/Unit</strong></th>
<th><strong>Total</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>$40.83</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Cost of Production/gallon**

<table>
<thead>
<tr>
<th>Cost of Production/gallon</th>
<th></th>
<th><strong>$/Unit</strong></th>
<th><strong>Total</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>$2.00</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Integrated Profit/Acre = Maintenance Savings ($30/Acre saved on mowing + Fuel Production Profit/Acre) = $30 + $10.83

*Integrated Profit/Acre/acre = Integrated Profit/Acre * 9.1 acres/acre = $40.83 * 9.1 = $372.03

*Cost of Production per gallon = (Total Costs - Integrated Profits per acre)/100 sales per acre = ($129.89 - $372.03)/26.0

*Custom Farming Values are rates expected to be charged for or paid, including fuel and labor. The average price for diesel fuel was assumed to be $2.75 per gallon. A fuel price increase of $0.50 per gallon will cause total machinery costs to increased approximately 5 percent. Actual custom rates may vary according to availability of machinery in a given area, timeliness, operator skill, field size and shape, crop conditions, and the performance characteristics of the machine being used.
The NTAL project has generated local, regional and national attention. Clearly soil, cropping systems and environmental conditions vary from region to region. As the NTAL model has matured, dissemination of this project’s research has led to interest from other entities. National interest in utilizing nontraditional agriculture lands for biofuel feedstock production has allowed partnerships with other departments of transportation, land grant universities, departments of agriculture and energy, financial development, sustainability groups, military and municipalities. This has encouraged the development of a national alliance between interested parties for developing NTAL projects in other parts of the United States.

**NTAL National Alliance**

It is anticipated that project partners, from other states and organizations, with successful production will remain as long-term biofuel feedstock sources in their respective regions. Various feedstocks need to be evaluated by scientific comparison of different agronomic cropping locations and a host of oilseed feedstock crops, under the management of various university partners, and guidance from Utah State University. Coalition, transportation and storage of these feedstocks will be conducted with conventional equipment.

Researchers should evaluate what planting methods/crop combinations will provide the most benefit to sustainable plant establishment and yield. Recommendations and implementation strategies will also be included in a final report to all partners and
disseminated at public forums and in scientific sources. A national NTAL alliance would promote beneficial collaboration across industry, government, and academia.

The NTAL Mosaic

It is obvious that all nontraditional agronomic lands are not suited for biofuel feedstock production. To mitigate this issue we feel the NTAL Mosaic concept should be pursued further. The NTAL Mosaic concept embraces issues related to:

- Safety
- Structural Integrity
- Establishment and Harvesting
- Financials
- Wildlife Impacts
- Ecology/Environmental Impacts
- Water Quality
- Local Grower Concerns

The NTAL mosaic would integrate these topics in nontraditional agronomic land settings seeking to reach a sustainable balance between variables introduced by the specific situations. One iteration of the NTAL mosaic would be to grow vegetation from the roadside to the right of way boundary in height steps. By design, low growing perennials would be closest to the road, and then taller crops could be grown in the next step of the mosaic. Finally, as risk factors become decreased with distance from roadside, taller or denser crops could be grown.
REFERENCES


Utah Department of Transportation (UDOT). 2007 Personal conversation


