WHITE PAPER

GPS Guidance and Automated Steering Renew Interest In Precision Farming Techniques

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Abstract

From 2001 through 2006, Global Positioning System (GPS) based machine steering has driven rapid, widespread adoption of new technology in agriculture. Fueling this rapid adoption are many tangible, proven paybacks resulting from growers' capital investments in such systems. As this adoption continues, many growers are discovering and adopting new agronomic practices, including some related to site-specific farming as it was originally conceived in the early to mid 1990s. As a result, many growers are considering (or reconsidering) numerous site-specific precision agriculture practices, for three primary reasons: 1) they clearly see real paybacks—including economic, environmental and sociological—from GPS-guidance and automated steering systems; 2) the cost of GPS machine control systems is decreasing; and 3) once growers have invested in such GPS systems, their incremental cost for testing and perhaps adopting additional precision farming practices is relatively low. This paper examines this industry phenomenon.

Keywords: Global Positioning System, GPS, precision farming, GPS guidance, assisted steering, automated steering, site-specific farming, precision farming, variable application rates, *Ag*GPS Autopilot, differential correction, DGPS, real time kinematic, RTK, OmniSTAR

Introduction

Since the mid-1990s, the Global Positioning System (GPS) constellation of 24 satellites orbiting 10,800 miles (17,500km) above Earth has caught the attention of farmers and urban dwellers worldwide.

GPS technology delivers a range of benefits and advantages to growers. As global markets become more competitive and an increasingly populated world reduces available farm land, GPS guidance is now being relied upon to drive productivity and efficiencies in agriculture—from ground preparation to fertilizer application, planting, spraying and harvesting.

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Trimble *Ag*GPS® systems include machine guidance and automated steering systems as well as field management systems. All can help farmers and agri-business firms improve productivity and profitability through improved machine efficiencies, savings in fuel, fertilizer, chemicals and labor, and better-informed decision making.

To better understand this increasingly versatile production tool that is rapidly being adopted by growers worldwide, a brief review of GPS for agriculture may be helpful.

GPS basics: It's all about time

The U.S. Department of Defense began developing the world's first GPS system in 1973. In 1978 the first 1,900 lb. satellite was launched into twice-daily orbit at a 55 degree angle to the Equator. These Block II production satellites are 17 feet across with solar panels extended. Each satellite contains a computer, four atomic clocks accurate to a billionth of a second (i.e., 0.000000001 second), and a 50-watt radio. Twenty four satellites orbit at an altitude of 10,800 miles. Six different "spreads" of four satellites each orbit 60 degrees apart where they pass over the Equator. With this configuration, at least five satellites are in view at nearly all times from any point on Earth.[1]

These satellites continuously broadcast data including the time (to 1 billionth of a second) and their precise location relative to Earth at that instant. On the ground, all GPS receivers contain a computer and an *ephemeris* (or almanac) which provides information about each satellite's location. A GPS receiver determines its position by continuously calculating its distance from three or more GPS satellites based on their time and location data—a process known as "triangulating." Some GPS systems can guide massive agricultural machines as accurately as +/- 1 inch (2.5cm) or closer from an established row while moving at speeds of 12mph (19km/h) or higher.[2]

During the early years of GPS, the Department of Defense intentionally degraded the quality and accuracy of Navstar GPS signals in the interest of national security through a process known as "selective availability." However, in May of 2000, a presidential executive order ended such degradation of GPS signals in order to make more widespread use of GPS practical for civilian use. This action allowed up to 10 times improved accuracy for civilian GPS receivers, including those used in agriculture.[3]

The round-about path of precision agriculture

Widespread commercial trials of GPS-based precision farming began in the mid-1900s. Initially, the focus was on site-specific techniques, where exact locations in the field were mapped for yield and then treated variably with farm inputs such as seed, fertilizer, lime and crop protection chemicals. The initial goal of precision farming was to increase farm profitability by using variable rates of farm inputs to increase yield and lower input costs. But with complex biological systems, widely differing farm management practices and erratic weather—among many other variables—this goal was difficult to achieve. Although some growers could show measurable benefits, many others were unable to realize any such gains that could be detected by their agronomic systems and management style.

This lack of predictability greatly hindered the adoption of site-specific precision agriculture, which had made its debut in the late 1980s. Evidence of this relatively low adoption rate is shown in USDA Agricultural Resource Management Survey (ARMS) data. For example, in the late 1990s, variable rate technology (VRT) was used to manage soil fertility—mainly N, P, K and lime—on nearly 18 percent of U.S. planted corn area[4]. However, ARMS data indicate that this rate was less than 10 percent of corn planted in 2001, and even lower on soybeans.[5]

As the definitive 2005 Purdue University study cited above notes: "Worldwide, the adoption of precision agriculture technology has been slower and more localized than many analysts in the 1990s expected."[6]

In addition, the study includes these relevant facts:

- **Yield monitor adoption:** In 2000, the U.S. had about 134 yield monitors per million acres (417,500 hectares) of grain or oilseed crops—or about one yield monitor per 7,500 acres (3,000 hectares). About 37 percent of these yield monitors were being used in conjunction with GPS.
- **Precision agriculture usage**: In 2001 (the latest year for which these types of ARMS data are available), the percentage of U.S. corn on which precision agriculture technologies were used included:

Practice	Percent of planted corn acres
Yield monitor	36.5
Yield map (yield monitor w/GPS)	13.7
Geo-referenced soil map	25.0
Remotely-sensed (e.g. satellite) image	3.4

- **Pesticide VRT increasing**: Variable rate technology for crop protection chemicals appears to be on the upswing, although overall adoption rates are still low (1–3 percent of acres treated), based on most-recent ARMS data.
- **Nitrogen VRT promising**: The most commercially viable on-the-go technologies for crop production at present focus largely on varying *nitrogen* fertilizer application rates within fields (as opposed to phosphorus or potash).
- **Economic returns from GPS systems are being measured and proved:** A separate 2002 study of GPS auto guidance concludes, in part, *". . . DGPS auto guidance will be profitable for a substantial group of Corn Belt farmers in the next few years. This will primarily be growers who are now farming as many acres as they can with a given set of equipment. The initial benefit for many growers will come from being able to expand farm size with the same equipment set. A $15,000 investment in DGPS auto guidance is a relatively inexpensive way to expand equipment capacity by several hundred acres."*[7]
- **Especially significant:** Overall, the costs of information technology hardware and software are continually *declining* as the productivity of such technology is *increasing*.

Rapid Adoption of GPS Guidance and Automated Steering

In contrast to variable rate technology, between 1999 and 2006 extremely rapid GPS-driven technology adoption took hold as demand soared for GPS-based guidance and equipment automation (or automated steering) systems. Massive adoption of various GPS systems to help guide and automatically steer farm machinery and implements—often to sub-inch levels—is becoming a technological and social phenomenon.[8]

The rapid adoption of these GPS systems is being driven by various factors, including the following:

- **Tangible payback** that customers receive from their GPS-based guidance systems, including improved in-field productivity, reduced crop inputs such as fuel, fertilizer and chemicals, reduced operator fatigue, and the ability to operate machinery longer hours.
- **Simple installation and operation.** For example, the Trimble *Ag*GPS EZ-Steer® assisted steering system requires only about 30 minutes and one wrench for the grower to install.
- **Lower cost** of guidance technology—noted previously. As with most new technology, especially electronics, the cost of GPS systems continues to decrease. For example, a Trimble *Ag*GPS Autopilot automated steering system with on-farm Real Time Kinematic (RTK) base station, offering +/- 1-inch (2.5cm) accuracy, typically cost about US$40,000 in 2004–2005. With the advent of new guidance ready (factory installed hardware and hydraulics) tractors and combines, and RTK base station

networks, the incremental cost of a similar system in mid 2006 runs as low as US$18,000.

Thousands of growers operating Trimble GPS guidance systems often report tangible benefits after the first few days of using their systems. As a result, more users are indicating interest in trying other aspects of precision agriculture. This phenomenon is generating a surge of interest in site-specific technologies such as yield monitoring and mapping, precision placement and rate control of crop inputs. Top managers and commercial applicators are also adopting data management systems that provide improved field record keeping with the aid of in-cab computers and data loggers. Such systems also fill a significant need for application mapping, accompanied by "proof of performance" data to meet increasingly stringent legal and environmental demands.

As a result, it now appears that the greatest opportunity to expand precision agriculture as originally conceived is to better inform and educate growers on the benefits of GPS-guidance systems. Once growers can actually measure the value returned by their GPS guidance or automated steering systems—in gallons of fuel saved, hours of reduced labor, additional acres covered per day, or dollars of additional grain, cotton, potatoes or peanuts sold—they feel comfortable about using these systems to further reduce costs and increase income. In other words, the satisfaction and confidence gained from a GPS-based guidance system makes it relatively easy for many growers to upgrade hardware and/or software in order to achieve more automation of their farming operation—all from within the cab.

Interestingly, GPS-based guidance systems often elicit multi-sensory responses from those who purchase and/or operate them: Such systems not only make it possible for managers to *see* economic returns on their equipment investment, they also make many growers *feel* as if they are in better operational and economic control of their operation than ever before.

Describing GPS Solutions Accurately in the Market

No matter what a farmer/operator's reason for investigating precision agriculture, it is important to understand the two key accuracy specifications.

Year-to-Year Accuracy (repeatable accuracy): The GPS receiver's ability to return to previously marked or mapped obstacles or run-lines (A-B lines) that need to be revisited a week, a month or a year later. Higher grade GPS receivers using dual frequency technology can be as accurate as +/- 1 inch (2.5 cm) and can be applied to operations requiring extremely precise field work such as the laying of drip tape directly in pre-formed beds, or strip applications of fertilizer followed by planting of seed directly over such strips of fertilizer. Only GPS receivers using Real Time Kinematic (RTK) technology can deliver +/- 1 inch (2.5cm) year-to-year accuracy or "repeatability".[9]

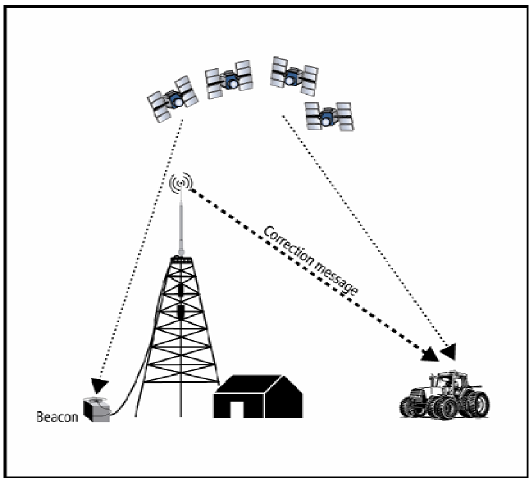
Pass-to-Pass Accuracy (relative accuracy): The GPS receiver's ability to provide accuracy within a field operation from one pass to the next (i.e., the accuracy relative to the previous pass). Typically, this specification is quoted by most manufacturers as pass-to-pass accuracy within a 15 minute interval. Good pass-to-pass provides even swath lines with minimum overlap and skip. Lower grade GPS receivers can provide pass-to-pass accuracy that is acceptable for operations such as tillage, spreading, spraying and harvesting. Typically a quality Differential GPS (DGPS) receiver will provide 6–12 inch (15–30 centimeter) pass-to-pass performance over a 15 minute interval.[10]

GPS Signal Correction Systems

Despite the elimination of selective availability in 2000, various GPS signal errors make special correction systems necessary for civilian GPS to perform at the accuracy levels demanded by agricultural machine operations. Without additional correction, GPS-controlled field equipment could deliver pass-to-pass accuracy of only about 6–8 feet (2–3 meters), with even less accuracy in repeat operations.

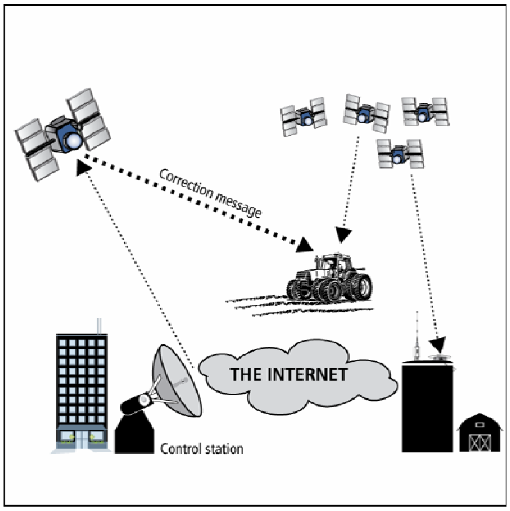
Fortunately, a range of GPS signal correction services is available that will fit most operators' agronomic needs and financial means. The three categories in most widespread agricultural use include:[11]

Differential GPS (DGPS) with Beacon Correction



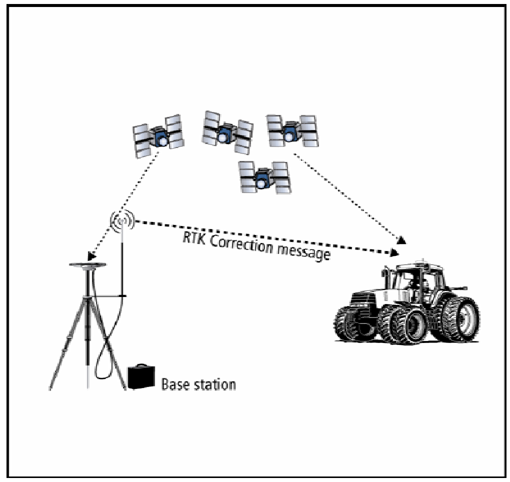
The vehicle (rover) with a GPS antenna receives GPS signals from the GPS satellite constellation. The Beacon receiver, at a known location, receives GPS signals. The beacon generates an equation that changes the location of where the GPS satellites *indicate* it is, to where it *knows* it is, and then sends the equation, known as the "correction message," to the GPS antenna on the rover—which then applies the correction.

Differential GPS (DGPS) with WAAS and OmniSTAR



The vehicle with a GPS antenna receives GPS signals from the GPS satellite constellation. The WAAS (Wide Area Augmentation System of the Federal Aviation Administration [FAA] is one example of an SBAS or Space Based Augmentation System. EGNOS is another example over Europe) and OmniSTAR services have many GPS receivers at known reference locations that send the correction messages to control stations which then uplink the message to a geostationary satellite (WAAS or OmniSTAR). The geostationary WAAS or OmniSTAR satellite then sends the correction message to the GPS antenna on the vehicle, which applies the correction.

RTK (Real Time Kinematic)



This highly precise technique results in one inch year-to-year and pass-to-pass accuracy. RTK GPS requires two specialized GPS receivers and two radios. One GPS receiver is set up as a base station within a 6 mile (11 km) radius of the field in which the rover is working so it can send the correction message to the roving receiver. Both receivers collect extra data from the GPS satellite L1 and L2 bands. This results in a much higher level of precision than is possible with other types of GPS signal correction.

Differences among DGPS, OmniSTAR and RTK signal correction[12]

Characteristic	DGPS Beacon and WAAS	OmniSTAR XP/HP	RTK
Satellites required for initializing	3 minimum; 4 required for sub-meter accuracy	XP: 5 HP: 5	5 minimum
Time required for initializing	Instantly	XP: 20–40 min. HP: 20–40 min.	About 1 minute
On-the-fly initialization to obtain centimeter accuracy while moving.	Not applicable	XP: Yes HP: Yes	Yes
Receiver	Single frequency sufficient	XP: Dual frequency HP: Dual frequency	Dual frequency
Accuracy	Sub-meter (Horizontal axis only)	XP: +/- 3–5 inch pass-to-pass; +/- 8 inch repeatable HP: +/- 2–4 inch pass-to-pass; +/– 4 inch repeatable	About 1 inch (2.5 cm) or better in horizontal and vertical axes
Base station requirement	Operator-owned, fee-based correction service provider, or free radio beacon broadcasts (e.g., Coast Guard or WAAS)	XP: None HP: None	Operator-owned, or fee-based network, with station or repeater not more than about 6 miles (10 km) from field system is operating

Real Benefits Renew Interest in Precision Agriculture

As more growers experience the benefits of GPS guidance, assisted and automated steering, new ways for them to adapt farming practices and equipment continue to emerge. Moreover, once a grower has a GPS guidance system there is often little incremental cost to add other precision agricultural capabilities. Other precision capabilities such as application rate control, yield monitoring or automatic boom section control are now possible via a single in-cab display. In other words, success begets success. Once the user has experienced payback and benefits from a GPS guidance or automated steering system, the relatively low additional cost of purchasing the other precision agricultural technology will encourage the grower to try out other precision tasks.

Because GPS removes the need to drive the vehicle, operators can focus on more complex operations occurring behind the vehicle. It is now common to integrate several operations into a single machine to reduce the number of passes over a field. Growers now routinely position seed to be planted at the spacing and position desired. It is even possible to cultivate within an inch of the plants to remove weeds or apply chemicals in a narrow band to reduce chemical inputs.

Looking ahead, precision automation of the agricultural vehicle and associated equipment is destined to be a key part of most growers' "best practices" that consistently make them more productive and more competitive. Manufacturers will also be drawn to the opportunity of improving vehicle designs, implements and pull-behind equipment to maximize the synergy of GPS technology on the farm.

Here are some examples of these benefits and changes to agriculture due to GPS guidance or GPS steering systems:

GPS Guidance and Automated Steering Systems Give the Grower More Time.

All guidance systems give the grower more time—either by helping them to do every job faster or by effectively extending the work day several hours.

For a father and son's 4,000 acre (1,618 hectare) cotton operation in Missouri, an *Ag*GPS EZ-Guide® Plus lightbar guidance system has helped maximize a precious resources—time.[13]

A Trimble *Ag*GPS EZ-Guide Plus lightbar guidance system was purchased in early 2004 and is used on their John Deere 4710 Highboy self-propelled sprayer. This combination enables them to finish spraying a 160 acre (65 hectare) field in 45 minutes traveling 17 miles per hour (27 kilometers per hour). With a total of 27 pivot irrigation fields, the EZ-Guide Plus allows them to work around the pivots without having to count rows, saving them significant time during the job. This operation also band sprays cotton with nozzles spaced at 19 inches—mostly insecticides, plus some harvest aids. The lightbar system reduces overlap and skip and makes it easy to spray 28 rows at a time with a 90–foot boom, with rows matched all the way across the field.

This same farm also runs two Trimble *Ag*GPS Autopilot systems using RTK GPS accuracy on their tractors for planting. After ripping and bedding six rows at a time, planting 12 38-inch rows and spraying 28 rows per pass to within one inch accuracy, they can then follow up with EZ-Guide Plus for spraying. Band spraying of the accurately-planted rows increases their savings. On average, they save between US$8.00 to $10.00 per acre by reducing over-application of chemicals using EZ-Guide Plus. They recouped the cost of the system two-fold in less than six months.

An Oklahoma cotton grower (name withheld at grower's request) lost all 6,200 acres (2,500 hectares) of three-week old cotton in a heavy rain and hail storm in June 2003—the cotton crop was essentially wiped out[14]. With his recent acquisition of two Trimble Autopilot RTK systems, the operation was able to work around-the-clock to replant most of his acreage.

Operating two planters (each at 12-row 30-inch units), the operation replanted 4,800 acres of cotton and planted 1,400 acres into sunflowers in less than four days. The replanted cotton crop yielded a respectable 1.53 bales per acre.

Precise Fertilizer and Seed Placement

There is a revival in the U.S. towards strip tillage. With GPS RTK technology using +/- 1 inch (2.5 centimeters) performance, the fertilizer is positioned in the furrow, typically in the fall. Later, usually in the spring, seed is planted directly over the strip of fertilizer. This ensures that the seed is close to the nutrients to help stimulate plant growth and development. With highly accurate RTK automated steering systems strip till is now a much more feasible operation for many growers, given its ability to place virtually all seed and fertilizer within a 1 inch (2.5 centimeter) band. After using a Trimble Autopilot RTK automated steering system for three years, one Iowa farming operation[15] reports a 30–40 percent drop in fertilizer costs and an 8 percent annual increase in yields.

Corn growers in Nebraska[16] switched their 3,300 acres of row crops from no-till to strip till in 2001. By using a Trimble *Ag*GPS Autopilot system, they can now be much more precise in holding the 16-row strip till machine and anhydrous tank on the correct row spacing, especially on their rolling ground. Previously if the strip tiller ran a little narrow in places and they tried planting a little narrow to match, they could end up with rows that were four inches apart on the "guess row" while other rows were far too wide. With *Ag*GPS Autopilot, they have noticed these improvements in their strip till practices:

- **Precise row widths—**their John Deere 8520 tractor can pull an 8-row strip tiller in the fall and 16-row planter in spring. Any combination of machinery rows will work, because all corn rows are now exactly the same distance apart.
- **Better seed placement**—they estimate that autosteer with strip till and planting has improved precision of seed placement so that the seed is dropped in the correct spot, even on hilly ground, an estimated 99 percent of the time.
- **Stronger stands**—fertilizer application is 80–120 lbs. of NH_3 (160 for corn on corn) with N-Serve per acre, 6 to 10 inches deep, with strip tiller. They usually begin mid-October and finish mid-November to mid-December. The following spring, final stands run from 22–23,000 dryland, and 28–29,000 irrigated, per acre—very close to planted populations.
- **More productive fieldwork**—the most senior member of the operation, more than 75 years old, does much of the strip till planting, running 100 acres between refills. He's been known to plant at night with tractor lights off, letting *Ag*GPS Autopilot alert him of upcoming turn rows and often planting 300 acres per day.

Controlled Traffic

It has long been documented that soil compaction has a negative impact on soil structure and crop yields. To control soil compaction, methods such as tramlines have been used in some parts of the world, particularly Europe and Australia. Now accurate automated steering systems that use RTK and deliver +/- 1 inch (2.5 cm) pass-to-pass and repeatable accuracy can deliver all the benefits of controlled traffic in addition to other automated steering benefits. To maximize the potential benefit from RTK controlled traffic, all farm vehicles to be used in the field need to have equal wheel spacing. Some top operators are now adapting fleet-wide wheel spacing to match that of their Autopilot RTK system, thereby minimize soil compaction. This includes Clay Mitchell, of The Mitchell Farm in Iowa, where all field equipment has identical wheel spacing; appropriately-sized tillage and planter toolbars, spray booms and harvester grain platforms or corn/soybean heads allow Mitchell's vehicles to follow established tramlines at all times.

Conclusion

The current adoption of GPS guidance, assisted steering and automated steering systems is encouraging thousands of crop growers to try new, innovative farm practices. These improved farming practices are made possible with the greatly improved precision and repeatability of various machine operations. This rapid GPS adoption phenomenon is helping to expand the adoption of precision farming practices at many levels, because users of GPS guidance or steering systems can now experiment with, and adopt, other precision farming tasks for a relatively small additional investment. Some of these practices are making such growers more productive, more responsive to the environment, more profitable, and thereby more competitive in the global market.

Sources

1. University of Colorado Web site www.colorado.edu/geography/gcraft/notes/gps gps.html
2. Trimble Navigation Limited, "What Autopilot Does, no human can match . . . ," *StraightTalk* newsletter, Spring, 2005 Issue, p. 1
3. The White House, Office of the Press Secretary, Statement by the President regarding the United States' decision to stop degrading global positioning system accuracy, May 1, 2000, p. 1
4. Griffin, T.W. and J .Lowenberg-DeBoer, "Worldwide Adoption and Profitability of Precision Agriculture: Implications for Brazil," Purdue University Department of Agricultural Economics Publication, August, 2005, p. 5
5. Ibid., p. 5
6. Ibid., p 18
7. Watson, Matt and Lowenberg-DeBoer, Jess, "Who will benefit from GPS Auto Guidance in the Corn Belt?", Purdue University Department of Agricultural Economics Publication, December, 2002, p. 4
8. Trimble Navigation Limited, proprietary marketing and sales statistics, 2000 through 2005
9. Berglund, S. and Buick, R. Guidance and Automated Steering Drive Resurgence in Precision Farming. Presentation & paper at 5th International Symposium on Precision Agriculture, 9-12 June, 2005, Uppsala, Sweden.
10. Ibid.
11. Trimble Navigation Limited, "GPS Explained," Trimble Precision Agriculture publication, August, 2005, p. 14
12. Bressler, J., and Kettle, L., personal correspondence with sources, June, 2006
13. Trimble Navigation Limited, "Haste Makes no waste for Trimble EZ-Guide Plus users," *StraightTalk* newsletter, Fall, 2004, Issue, p. 1
14. Trimble Navigation Limited, "What Autopilot Does, no human can match . . . ," *StraightTalk* newsletter, Spring, 2005 Issue, p. 1
15. Clay Mitchell, The Mitchell Farm, Buckingham, Iowa, personal correspondence with source, 2004–2005
16. Trimble Navigation Limited, "Autopilot takes stress out of strip till on slopes," *StraightTalk* newsletter, Fall, 2004, issue, P. 3