My brother and I farm about 3500 acres of mostly wheat in the foothills of the Blue Mountains near Dayton, Washington. We began converting from plowing and cultivating to no-till in 1997, and have operated completely without tillage since 2000.

Precision-farming tools began to be available in our area about 1993, and ever since then we have experimented with whatever we could afford that looked interesting. This is the story of what we have found to be useful, and how we have consequently changed our thinking and adapted our practices to become, we hope, better farmers.

COMPOST
Our farm covers elevations from 1600 to 3200 feet. There are ridges, canyons, knobs, and swales. There is no flat land; there is no level land; there are no straight field boundaries. All the farmland is classified as highly erodible. As a result, never since the invention of the term “precision agriculture” has the idea appealed to us that we should take soil samples in a grid of square parcels. Instead, we have used aerial photographs to identify anomalous areas, and have used GPS to guide us to typical spots in those areas for soil samples. This method assures adequate characterization of the farm by taking a few samples in carefully chosen sites, rather than by flooding it with sample sites chosen blindly. Our money can be well spent by sampling those few sites year after year. With GPS guidance, we can be confident that year-to-year variations in sample results are a consequence of our farming practices.

Over the years, we have long suspected that organic matter levels in our soils have been declining. With GPS guidance and computerized record-keeping, there is no longer any doubt. Aren’t computers wonderful? We never really knew anything for sure, before. “This year is probably a little lower than last year,” we blithely rationalized, “because we didn’t sample in the same place; and I can’t remember anything farther back than last year; so what the heck, we must be doing fine.”

But we’re not doing fine. With the soil’s history at our fingertips, we realize we cannot continue as we have. One of the practices we have instituted in an effort to halt the decline of soil organic matter is application of compost. We grow seed peas for a local processor. They return the rejects—cracked peas, dirt, foreign matter—to our compost pile. Periodically we spread the compost over areas of the fields that have low organic matter, or some other identifiable insufficiency. Aerial photos and yield maps make it easy to identify such areas; and GPS guidance makes it easy to evaluate the treatments.

Compost is not a panacea. For example, the composting process seems to lower the nitrogen content and raise the salt content. Certain sensitive crops such as barley and legumes will not grow on recently composted soil. Maybe we shouldn’t compost at all, but should spread the stuff on the fields immediately, before the fertility value is lost. On the other hand, there are unmistakably favorable trends in evidence. Areas such as old, dead furrows and eroded knobs, which once produced nearly nothing, have been returned to average production. Some composted areas do not require fertilizing for at least 3 years after the application. The compost itself, being only a thin layer, does not change the soil’s organic matter; but the extra crop residue from improved growth does. Direct-seeding leaves this extra residue alone, to eventually be incorporated by microorganisms into the soil structure. Soil tests now indicate that in the last 3 years, organic matter in most places has ceased its decline.

One interesting sideline accruing to the use of aerial photos is a better understanding of what soil types are associated with various terrain features. It was once accepted wisdom that erosion moved topsoil from high to low, and therefore ridgetops would have the lowest yields. That is sometimes true, but we have identified equally low yields on mid-slopes, where sharp underground basalt cliffs come extra close to smoothly contoured soil surfaces; and on drainage bottoms, where nutrients seem to be carried away faster than crops can use them, despite the deeper soil.
LARGE-SCALE FIELD PLOTS

We have never questioned the obvious truth that conclusions based on results of atypical experiments, cannot themselves be typical. In the past, we conducted atypical experiments anyway because there simply was no alternative. Experimental plots were established on small, level areas next to the road, because, as one scientist put it (edited for family values), “you couldn’t pay me enough to take my combine onto that hillside.”

Now, with photo guidance from the air and GPS guidance on the ground, we can do better. Entire fields of hundreds of acres can be divided into plots that encompass all manner of identifiable variables. Without seriously impeding the normal mechanics of farming, different plots can be treated differently (by computer control of seeding rates, fertilizer rates and types, weed treatments and timings) and evaluated separately by yield map.

In this manner, we have investigated seeding dates and phosphorous starter fertilizer for effectiveness in overcoming slower plant growth typical of the cooler soils of the no-till process, and interactions between nutrients generally thought to have independent effects.

Legume yields on our farm have generally declined since we made the transition to no-till. In the past, our philosophy has been to seed as early in the spring as possible, so the crop will set seed before hot summer weather. Early seeded legumes now seem to emerge handily enough, but then languish until overtaken by weeds and diseases. Perhaps, we speculated, later-seeded legumes would grow enough faster in warmer soil with a more favorable microbial community, to make up for lost time and still beat summer’s heat. We documented this experiment with aerial photos taken several times throughout the growing season, eventually overlaying them on the yield map produced at harvest. The expected trend was evident: early seedings were overcome with weeds and produced nearly nothing. Late seedings were overcome by summer heat and produced only worthless shrivels. Mid seedings grew well and produced satisfactory yields of good quality. I bring this up as an example of what can easily be accomplished with inexpensive equipment and fairly efficient field operation; but the unfortunate fact is the experiment was a failure because the effects of soil temperature cannot be reliably separated from the effects of green-bridge disease control.

We first noticed the possibility of interacting chemicals when an ammonium sulfate spreader inadvertently ran across a set of micronutrient plots. A spot of exceptionally high yield showed up on the yield map of the potassium strip at precisely the point where the spreader crossed it. (See how wonderful technology is? We would have dismissed that high-yield spot as a random unknown if the tractor pulling the spreader hadn’t been equipped with recording GPS. Of course, if the driver had been paying attention in the first place, he wouldn’t have run over the plots.) Subsequent field experiments have demonstrated that extra nitrogen alone, or extra potassium alone, have no effect; but potassium enables a wheat plant to use extra nitrogen. The effect is pronounced enough to be economically advantageous on poorly drained soils at the higher elevations of our farm.

STUBBLE BURNING

It is our opinion (or fear) that politics being what it is, agricultural burning will soon be declared criminally harmful, factual evidence to the contrary notwithstanding. Therefore, while we remain avidly interested in results of direct seeding systems of all kinds, we personally are determined to do the best we can without burning our stubble. To this end, we are understandably overeager to report any evidence that makes it seem we are doing the right thing. Here is an example of turning a disaster into a learning experience. During winter wheat harvest, a hot exhaust pipe started a fire that burned 10 acres of standing grain. For insurance purposes, the destroyed area was thoroughly documented with GPS tracks and aerial photographs. We subsequently treated the entire field, burned or not, as one, direct-seeding a spring wheat crop the following April. No concessions were made whatsoever to the fact that part of the soil was covered with heavy stubble from a 101-bushel crop, and part was burnt completely bare. The following spring was drier than normal. The spring wheat crop thrived on the extra moisture held over from the winter in the stubble-covered soil, but dried up and died in the bare soil. Seventy bushels per acre, versus ten bushels per acre, grew in a thoroughly documented (if accidental) side-by-side comparison.
It has now been 4 years since the fire. The boundary of the burned area is still visible in aerial photos, though the adverse effect on yield has dwindled to unmeasurable. Scary as it may be to be confronted with the fact that every little thing we farmers do has long-term effects, we must not shy from our responsibilities as caretakers of a valuable natural resource.

**YIELD MONITOR**

We have quite a few years of hands-on experience with combine-mounted yield monitors and yield-mapping software. One thing is pretty certain. If you drive your combine as if it had no yield monitor, and if you unquestioningly accept what the computer gives you for a map, then yield is not what you’re measuring. The field operator must take care to make every pass across the field the same as the previous pass: same direction, same speed, constant speed, same width of cut. Stay on the contour: do not harvest uphill or downhill. Any deviations must be noted and accounted for in the subsequent mapping process, because foibles within the combine itself will cause data variations that swamp true changes in yield.

Still, with care, it is possible to get useful information from a yield map. Evaluation of field-sized plots would be inconvenient, to say the least, without a yield monitor because one would have to haul a weigh-wagon to inaccessible spots, or spend time dragging the combine back empty. One effective use of the monitor is to pay attention only to relative changes in yield, and to convert to an approximate absolute yield by deriving a calibrating scale factor from warehouse receipts.

We also have found aerial photos taken during a crop’s critical development stage provide an excellent indication of subsequent yield. Thus, the photo can be overlayed with the yield map as a check on the map’s reliability; or can even be used instead of a yield map if no other data are available.

Yield maps, or the equivalent photos, are an excellent way to develop a historical database of a farm’s productivity. Some areas do poorly, year after year, in all kinds of crops. These areas can be investigated closely, using GPS guidance from coordinates derived from the maps. Perhaps the problem is poor drainage, soil compaction, chemical drift due to consistent wind patterns, insect pressure from adjacent outground, or thin soil over a hidden basalt outcropping. Not especially useful, but nonetheless interesting, is the discovery of patterns leftover from the places where, 130 years ago, one’s great-grandfather had his apple orchard or his hog pen.

Some areas might do well in one crop, but poorly in another. We have several times seen evidence that when a legume crop follows a wheat crop, areas of the field that did poorly in wheat, subsequently did well in the legume, and vice versa. I’m not sure I understand this phenomenon yet. The most common reason for wheat doing poorly is lack of moisture; and the most common reason for lack of moisture (in an isolated area) is thin soil. But shouldn’t thin soil adversely affect the legume crop, too?

**FIELD NAVIGATION**

We have already mentioned several uses of a GPS receiver. With aerial photos tied to geodetic coordinates, any anomalies in the photo can be investigated closely by visiting the corresponding location on the ground. Similarly, anything noted during ground investigation can be outlined on the photo. Localized farm operations such as soil sampling sites or isolated weed treatment patches can be monitored over long periods, because GPS enables one to return to the same spot over and over, year after year.

We have mapped areas of Canada thistle, morning glory (field bindweed), skeleton weed, jointed goatgrass, and cheatgrass (downy brome), to better understand how these weeds spread, and how best to combat them. Weed maps are actually fun to make: from the cab of the combine or tractor, just push the button appropriate to the sighting. It’s great entertainment for young passengers. For that matter, once the Mariners game is over on the radio, it’s pretty good for the old guys, too. You may be sorry GPS was ever invented: the cheatgrass and goatgrass battles are lost, I’m afraid; but news from the other three fronts is encouraging.
Variable rate applications are easy with GPS. Once areas needing special treatment are identified from aerial photos or by ground investigation, the necessary equipment adjustments can be made on the fly, either automatically under computer control, or manually by having the operator watch the equipment’s field position on a live display. We have Raven controllers on our drill and our sprayer. We have demonstrated automatic computer control of the drill, but so far we have found it kinda spooky to be under the influence of something that mysterious. So we mostly use the manual method.

The other major use of GPS is for guidance of field equipment. In this regard, to each his own; but I personally have found the seemingly popular GPS-driven lightbar is hopelessly counter intuitive. We do not raise row crops. Perhaps if we did, and perhaps if I were looking out my cab window at a set of clearly visible parallel lines, then I could take the appropriate action when informed (for example) that I was 2 feet to the left of course. I would know that rows are (for example) 1 foot apart, and I would look out the window and turn my steering wheel to the right until I had scooted over 2 rows, and straighten the steering wheel, and look at the lightbar again, knowing that my action had pretty much fixed the problem and it was now just a matter of fine tuning.

The problem we typically encounter on our fields in this area is much different. We pull an 80-foot sprayer, so the mark we are trying to follow is 40 feet away. The foam marker we use, under ideal conditions, is marginally visible. The mark we are following is never straight, because the field boundaries are not straight to begin with, and they get more crooked with each successive pass. The field is a uniform sea of untracked yellow. Now what do I do when informed (by a lightbar) that I am 2 feet to the left of course? Jog to the right? How much is 2 feet? What if the mark jogs 2 more feet to the right during the distance it takes me to jog 2 feet? Should I jog quickly or slowly? What if the mark is about ready to jog 2 feet to the left, so my jogging 2 feet to the right will make my error worse instead of better?

I am a licensed airplane pilot. In the flying world, the above conundrum leads to what is known as “pilot induced oscillation,” which is a fancy way of saying, “anything you do will make it worse.” Pilots are taught the following solution: do nothing. Hold a straight course, and watch the lightbar. If it gets better, continue to do nothing. If it gets worse, try turning a little bit right, and see if that slows down the rate at which things get worse. After years as a pilot, one eventually develops an intuitive feel for how much of an error can be safely ignored, and how quickly one must react to those errors which cannot be ignored.

But that was before GPS. What nonsense that with perfect knowledge of our position, we should still have to put up with the same old uncertainties. Instead of a lightbar, I prefer a moving map. My computer screen shows my position and the direction I am going, on a background of my past track. In principle, I can see at a glance that I am 2 feet left of course. But more importantly, I can see what my mark is doing, so I can predict what my future steering corrections will need to be, and can appropriately temper my immediate steering correction.

In actuality, my GPS receiver is accurate to about 10 feet; clearly, GPS alone cannot prevent me from making sprayer skips and overlaps. But it does keep me in the ballpark, giving me advance notice of sharp turns, so I will never drift so far as to miss seeing the next blob of foam that keeps my track fine tuned.

One further complication needs discussing. GPS knows your position, but it does not know your speed or heading. Position is measured directly, but speed and heading must be derived by the rate at which position is changing. Necessarily, then, speed and heading indications are always old. No matter how quickly GPS can calculate positions, speed and heading are from something you did, not from what you are doing. In my example of the 80-foot sprayer, this becomes an almost insurmountable problem when the sprayer comes to a corner and begins a turn onto a new course. At this time, the mark is way, way behind you, and hence invisible, so the operator is literally flying blind. The progress of the turn is being faithfully mapped on the computer screen; but if you roll out of the turn when the screen shows you to be on the correct heading, you will be too late, since it is physically impossible for GPS to know anything other than what the heading used to be.
The solution to this problem is fairly simple: get a compass. Mine cost less than $50. It has no moving parts, so bouncing around in the tractor doesn’t bother it much. The tractor cab is mostly glass and plastic, so stray magnetic fields don’t bother it much. Since it measures heading directly, it can tell you where you’re pointed as soon as you point there. Now my moving map shows my position (according to GPS) and my heading (according to the compass). I can even come to a complete stop, adjust my articulating tractor to point in the right direction, and start up again, knowing exactly where I will be going. This method is not possible with GPS alone, since GPS has no idea where you will be going unless you are already moving.

SERENDIPITY
We always hear we need a yield monitor so we can find the bad spots. We need a GPS receiver so we can map our fields. The result is known. The result is good. Therefore we should buy the equipment.

What if the result is not known? Maybe we should buy the equipment anyway. Who’s to deny the lure of peering over the next hill? Maybe you’ll get lucky.

In 2002, a field of lentils developed dense patches of dog fennel (mayweed). Seen from the ground, our usual scouting method, these patches were just weeds, mysteriously growing out there somewhere, as weeds do. “Well, darn,” we would once have said, shrugging our shoulders. “Guess next time we’ll have to use a different chemical, or spray twice, or plant a more competitive variety;” or speculate on any number of other things that we do because we can, without really having any idea what will or won’t work. But this time there was an aerial photo: it was strikingly obvious that the weeds were growing in triangular patterns that could only have been made by some field operation. We used GPS records from tractors and combines to establish that the weed patterns matched the track of the combine harvesting barley in 2001. Apparently, chaff rows were sheltering new weed growth from our glyphosate spray applications, but only in areas such as tapering corners where chaff rows tend to bunch together. This suggests a new method of weed control that doesn’t involve the expense of extra chemical: change the angle of a harvesting operation so the corners move to new spots.

Also in 2002, a field of spring barley turned sickly from rhizoctonia. Data on this soil-borne disease are hard to get; experiments are time-consuming and expensive, sometimes involving the legwork of mapping individual infested patches for several years to learn how it lurks and spreads. Mostly the news is lousy; and this time, the extra information we gained from technology is no real help. But it’s interesting and thought-provoking. Investigation from the ground indicated, as is always the case with rhizoctonia, that not all of the field was infected. Aerial photography showed the healthiest barley was in a stripe through the middle of the field, a stripe with edges so nearly straight as to make us believe it highly improbable to have been caused naturally. Our GPS field records don’t go back far enough to help with this one, so we had to piece together a solution from written descriptions and old photographs. The stripe is an old field boundary. Several times since 1990, that stripe has grown a crop different from the field to the south; and several times that stripe has grown a crop different from the field to the north. But at no time has the stripe grown a crop different from both adjacent fields at once. It seems unlikely, then, that any particular crop would have caused the stripe to stand out distinctly from both adjacent fields. In 1996 the three fields were incorporated into a single field, and the boundaries defining the rhizoctonia stripe have largely vanished. Except in 1998, which was the last time the field was tilled before our complete conversion to direct-seed. The whole field was chiseled, then fertilized with a rake-like applicator, which caused some straw to pile up in bunches. So, our written notes indicate, we did more chiseling in selected areas to spread around the bunches. An aerial photo from shortly after that date confirms the extra chiseling occurred precisely within the boundaries of what would 4 years later become a rhizoctonia-free zone. Our written records fall short of providing us with a complete solution to the mystery: why did the straw pile up only in that stripe, which for the 2 previous years had been treated identically with its surroundings? Nevertheless, it seems clear that in 2002, rhizoctonia suddenly appeared everywhere in a field except in the one spot that had been heavily tilled 4 years earlier.
16

SATELLITE PHOTOS

This paper has described numerous examples of useful information obtained from aerial photographs, so it should be obvious I think aerial photography is an important tool for farmers. As I have mentioned, I am a licensed pilot. I own an airplane, a GPS receiver, and a digital camera. The aerial photos I use for farming are the ones I have taken myself. The digital camera is the perfect instrument for the job: the photo is immediately stored in a computer and manipulated to match GPS coordinates for overlaying with ground investigations, maps, or other photos. My software is free, my camera and GPS are cheap, and I can photograph my entire farm in a half-hour, whenever the weather is to my liking; if only the expense of the airplane is considered, this amounts to a few cents per acre.

Most farmers think aerial photographs are not available to them because of expense. Indeed, the professionals who fly for the USGS carry cameras with million dollar lenses in billion dollar airplanes. Some farmers think that aerial photographs are unnecessary because pictures of their farms are free on the internet. Indeed, the mosaic carried by TerraServer covers the entire United States to a resolution of 3 meters, in black-and-white, at times varying from 6 to 10 years ago. In my opinion, neither of these objections should prevent a determined farmer from getting the information he needs in a timely manner. For example, local flight schools could put the equipment in their trainer airplanes, and students could click the shutter a few times while they were out practicing turns, stalls, and slow-flight. Farmers and students could share the cost of the airplane; farmers would get the photos, and students would get the flight time toward their license. Everybody would win.

Satellite photos are an alternative to aerial photos. With the help of Fran Pierce and his co-workers at the Precision Agriculture Institute, we have examined several Landsat satellite infrared photos of our farm, and compared them to ordinary aerial photos taken at nearly the same time of year: April 2002. The Landsat photos are 15 meters resolution, or about 50 feet. The images have three colors: near infrared appears red, red appears green, and green appears blue. April is not the best time of year to see how things are growing, but we had to take what we could get. Here are a few observations about the comparison.

The satellite photos can detect large spray skips. Weedy areas substantially larger than 50 feet on a side show up as red spots against a blue-green background. The theory is actively growing green plants reflect a higher fraction of near-infrared wavelengths than anything else, and hence appear bright red in photos that have been enhanced to emphasize those wavelengths. These same weedy areas also were clearly visible on the aerial photos, although in that case, of course, they showed up as green spots against a dirty-yellow background of decaying stubble.

The satellite photos cannot detect small spray skips. Nothing much smaller than the 50-foot photo resolution shows up, whether it’s actively growing or not. The aerial photos, with their 10-foot resolution, can detect such things as the spot where the truck was parked during the last rainstorm, because it’s drier there and the crop is growing more slowly.

The satellite photos are not very good at detecting subtle color differences in large areas with nothing actively growing. Aerial photos taken in April clearly show where goatgrass was bad in the previous fall’s winter wheat crop, because the goatgrass stubble is a slightly different color than the wheat stubble. This goatgrass patch did not show up on the Landsat photo despite being substantially larger than 50 feet on a side. Unfortunately, aerial photos from the previous spring, when the knowledge may have done us some good, did not show the actively growing goatgrass as distinct from the actively growing wheat.

Concerning the emphasis on near-infrared wavelengths in the Landsat photos, the following two facts should be noted. First, ordinary digital cameras are just as sensitive to near-infrared wavelengths as are the Landsat cameras. Since ordinary photos are not specially processed to emphasize those wavelengths, actively growing green plants still look green in the photos, but the shade of green is much brighter and easily distinguishable from the duller green of dormant objects. This fact can be quickly demonstrated: I scattered fresh grass clippings from my lawnmower onto the roof of my chickenhouse, which has grass-colored green shingles. From a distance to the...
naked eye, the clippings blend perfectly and are invisible; while in the photo from the digital camera, the clippings stand out dramatically.

Second, stubble reflects infrared wavelengths every bit as well as do actively growing green plants. On a direct-seeded farm with no stubble burning, this unfortunately means there is almost no time of the year when valuable information about a crop can be gleaned from remotely sensing the infrared wavelengths. And even if there were, the same information could be obtained from an ordinary camera.

Therefore, in the comparison with aerial photos from a simple, cheap camera, I am forced to conclude that the advantages of satellite photos—infrared sensitivity and an all-seeing vantage point—are far outweighed by the disadvantages—poor resolution, lack of timely availability, and greater expense.

**GPS CONTOUR MAPPING**

There are two instances where very accurate knowledge of a dryland farm’s elevation contours is important. First, the process of tying an aerial photograph to geodetic coordinates needs contours to remove the distortions that arise because the camera in the airplane is not always looking exactly straight down. Second, crops and weeds both grow differently depending on where the moisture collects and where the sun shines, and therefore, indirectly depending on surface slopes and other topographic features, which typically are derived from elevation contours.

Typical inexpensive GPS receivers are far less accurate in measurement of elevation than in measurement of latitude and longitude. So much so, in fact, that GPS elevations are useless for the two instances just mentioned.

Elevations are available for free on the internet for the entire state of Washington (probably for the entire United States as well, but I haven’t specifically looked) in the form of data sets pretentiously known as “digital elevation models,” which essentially are simply a scanned version of USGS quadrangle maps. These DEM’s are accurate enough to do a decent job of removing distortion from aerial photos, but they are not accurate enough to depict slopes and topographic features that affect crop growth. Perhaps “precise enough” is a better term than “accurate enough” to describe the deficiency. Even if you know exactly where every 20-foot contour is, you do not necessarily have enough information to map (for example) a 19-foot ditch.

One way to get good slope information is to hire a professional surveyor to accurately measure elevation at numerous closely spaced sample points covering the area to be analyzed. If the samples are accurate enough and spaced closely enough, then slopes can be computed by taking the derivative of a smoothed elevation function. This method works well, but from the standpoint of the farmer as opposed to the researcher, it is too tediously time consuming to be practical on a large scale.

One reason elevations must be taken so accurately and so closely in the professional-surveyor method is that the mathematical process of computing slope from elevation is inherently noisy, meaning errors are magnified. To derive a slope accurate to 10%, it is necessary to measure elevation accurate to 0.1%. If it were possible to measure slope directly, instead of deriving slope from elevation, then to get an accuracy of 10%, it would only be necessary to measure accurate to 10%. (That came out sounding kind of stupid, didn’t it?)

And it is possible to measure slope directly using small gages. They’re called “Tilt-o-meters,” and they cost a few dollars each in the “things you didn’t know you needed” catalogs. I’ve had them in my tractor and combine for years, and never realized I was missing a golden opportunity to effortlessly collect valuable data. If the computer that already records GPS position and compass heading were to also record tilt, I would need only to drive over a field once—which I have to do anyway for harvest or seeding—and voila! a ready-made, accurate contour map for use in analyzing the effect of terrain features on crop growth.

Stay tuned. Thank you for being interested in our efforts to make precision agriculture a useful farming tool.