

# INTEGRATING VARIABLE RATE TECHNOLOGIES FOR SOIL-APPLIED HERBICIDES IN ARIZONA VEGETABLE PRODUCTION

*Kurt D. Nolte, Mark C. Siemens and Pedro Andrade-Sanchez*

## Variable rate technologies and the application of preemergence herbicides

Since the mid 1990's, advances in global positioning systems (GPS), microprocessors, actuators, controllers, plant/soil sensors and geographical information systems (GIS) have spawned the development of new, site-specific, variable-rate techniques for chemical applications. At the same time, agricultural production has embraced other new technologies that increase the productivity of mechanized operations such as tractor auto-guidance systems. The combination of automatic tractor steering and variable rate technology is well suited for site-specific application of pre-emergence herbicides. With tractor guidance control and variable rate controllers, growers can increase the efficiency of chemical application by eliminating swath overlap, while increasing the efficacy of herbicide action by applying optimum rates based on soil texture.

These technologies have primarily been adopted by growers of major crops such as corn, wheat and soybeans (Koch and Khosla, 2007). Recently however, Arizona vegetable producers have become increasingly interested in using these technologies for variable rate application of soil applied preemergence herbicides. In many fields where vegetables are grown in Arizona, there is large spatial variation of soil properties, including soil texture. In fact, Bauer and Schefcik (1994) found that recommended application rates of preemergence, soil applied herbicides can vary as much as 50% in a given field due to varying soil textures.

## Soil properties influence preemergence herbicide effectiveness

Soil-applied preemergence herbicides are widely used in vegetable production for controlling weeds during stand establishment. These types of herbicides are used to control weeds after sowing, but prior to crop emergence. In vegetable production, they are typically broadcast applied to the soil surface and then incorporated into the top several inches of soil. After weed seed germination, the herbicide is absorbed by the roots and/or shoot of the seedling. This kills the weed

seedling, typically before it emerges from the soil. Contrary to conventional wisdom, preemergence herbicides do not kill plants by preventing seed germination.

After a herbicide has been applied to the soil, it has one of three fates. It can either remain dissolved in the soil solution, be adsorbed by smaller soil colloids or be absorbed by plant roots and shoots (Fig. 1). Herbicide that is adsorbed by soil is "tied-up" or bound to the soil and is not readily available for weed absorption. Soil properties that affect soil adsorption can include the presence of mineral oxides, soil organic matter

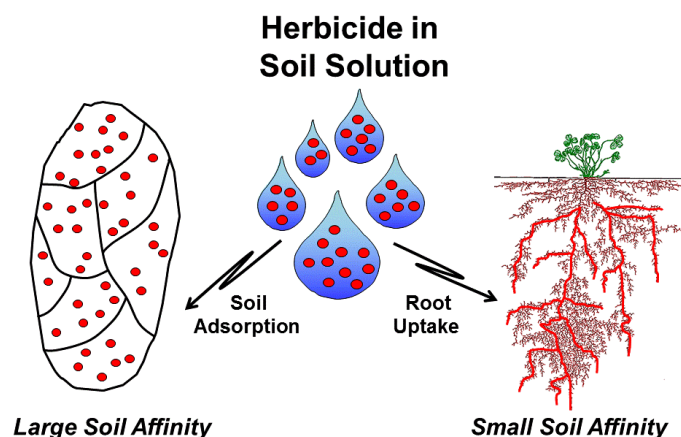


Figure 1. Effectiveness of soil applied herbicides can depend on the physical properties of the herbicide, soil organic matter content, and soil texture. When herbicides have a strong affinity to soil. They are less effective for weed control.

and clay composition, the level of crop residues in the soil, soil pH and soil water content. However, typical of western soils with high clay and low organic matter contents, the amount of herbicide adsorbed by most Arizona soils is highly dependent on the soil's clay content—the higher the clay content, the greater the amount of soil adsorption (Moomaw et al., 1992). Because of this, recommended rates for soil-applied herbicides are commonly based on soil texture. Herbicide adsorption to soil can be described using soil/organic matter ( $K_{oc}$ ) and soil/soil solution indices ( $K_d$ ). Both parameters are defined as the ratio between the level of herbicide adsorbed by a reference and the amount found in soil solution. Herbicides with high

Table 1. Physical properties of common preemergence herbicides used in Arizona vegetable production.

Product Name	Common Name	Water Solubility (ppm) <sup>1</sup>	Herbicide Soil/Solution Distribution Index ( $K_d$ )	Herbicide Soil/Organic Affinity Index ( $K_{oc}$ ) <sup>1</sup>	Soil Half-Life (days) <sup>1</sup>	Mobility Rating <sup>1</sup>
Balan® 2.5-G	Benefin	<1	16.7 – 48.6 <sup>2,3,4</sup>	9000	40	Extremely Low
Kerb® 50-WSP	Pronamide	15	6.2 – 15.4 <sup>2</sup>	200	60	High
Prefar® 4-E	Bensulide	6	5.4 – 13.5 <sup>2,5</sup>	1000	120	Moderate

<sup>1</sup>Weed Science Society of America, 2007

<sup>2</sup>Weber et al., 2000

<sup>3</sup>Jacques and Harvey, 1979

<sup>4</sup>Weber, 1990

<sup>5</sup>Carlson et al., 1975

sorption indices are typically prone to soil adsorption when applied in soils high in clay or organic matter content. This reduces herbicide available for root uptake in the soil solution, and higher herbicide application rates are needed to increase soil solution herbicide concentrations for effective weed control. When the same high herbicide rates are applied to soils with low clay content, less herbicide is adsorbed by soil and crop injury can result from excess herbicide in the soil solution. For herbicides with low sorption indices, herbicide effectiveness is much more consistent and less likely to cause crop injury problems since the herbicide is not readily adsorbed by soil.

The three most common soil incorporated preemergence herbicides used in Arizona vegetable production are listed in Table 1 along with the physical properties that are most important to their fate in soil. Of these, benefin (Balan®; active ingredient, N-butyl-N-ethyl- $\alpha,\alpha,\alpha$ -trifluoro-2,6-dinitro-p-toluidin) requires the most critical consideration of soil texture when determining the proper application rate to use. The herbicide has a very high soil sorption index making it strongly adsorbed by soil colloids and highly immobile. In soils with high clay content, a greater amount of the herbicide is required for adequate weed control as compared to sandy soils. If rates necessary for good weed control in high clay content soils are used on sandy soils, excessive herbicide concentrations in soil solution can cause injury to lettuce seedling roots (Tickes and Kerns, 1996). This high concentration problem is not easily resolved since Balan® has an extremely low mobility rating and is relatively insoluble in water, and therefore not likely to leach below the depth where crop seedlings develop.

## Yuma Case Study: Site-specific herbicide and variable rate delivery

The feasibility of site-specific, variable rate application strategies for preemergence herbicides in vegetable production was investigated on a commercial lettuce field near Yuma, AZ. The main objective of this work was to quantify and demonstrate the benefits of variable rate technologies for mediating the damage caused by the over application of the herbicide Balan® across non-uniform soil textures. Typically, candidate fields for variable rate technologies are chosen based on past experience with herbicide injury and the variable

nature of soil textures within a field. Prior aerial imagery of the field may also indicate distinct zones of non-uniformity. The twenty acre field used in this study was selected because the field had significant variability in soil type and the grower-cooperator had experienced some form of crop injury when applying uniform rates of soil incorporated herbicides in previous seasons.

To generate a site specific application map, a 2½ acre grid sampling scheme was used to prepare a geo-referenced soil textural map based on soil saturation percentage (SP). Saturation percentage, expressed as grams of water required to saturate 100 grams of soil, is a variable correlated with soil texture (Peacock, 1998) where the higher the SP, the greater the soil clay content. The experimental field was composed of three distinct soil textures: sandy clay (SP=49%), sandy clay loam (SP=32%) and loamy sand (SP=18%). A herbicide application rate map was created (FarmWorks Site Software, Trimble Navigation, Limited) based on soil texture with zones having the highest clay content (sandy clay) receiving greater rates of herbicide (2.5 lb ai/acre) than loamy sand areas (1.5 lb ai/acre) (Fig. 2). The sandy clay loam region in the field was assigned to receive an intermediate level of the herbicide (2.0 lb ai/acre). The intermediate rate was also applied within each soil textural zone and served as the standard treatment.

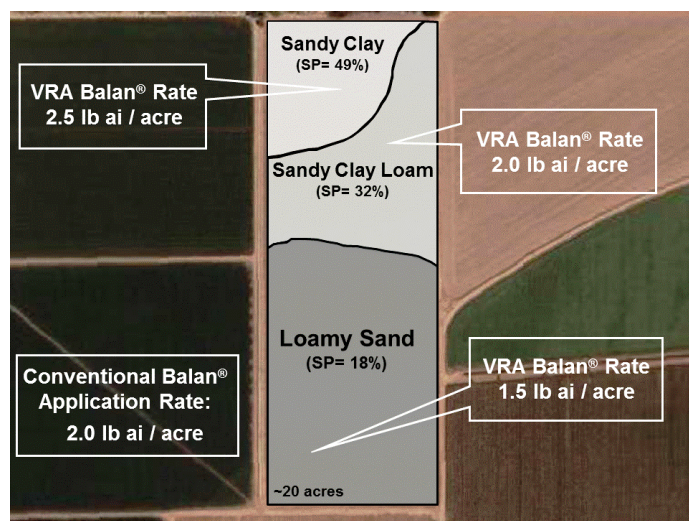


Figure 2. Site-specific Balan® application rates used on a twenty acre commercial lettuce field near Yuma, AZ based on a geo-referenced soil textured map. A standard rate of 2.0 lb ai/acre was used as the control application rate.

Table 2. Influence of standard and variable-rate Balan® application treatments on cumulative weed emergence per plot at two and four weeks post-germination.

Soil Texture	Balan Rate and Application (lb ai/acre, application method)	Total Weeds (number/plot) <sup>1,2</sup>	
		14 DAG <sup>3</sup>	28 DAG
Sandy Clay	2.0, standard	3.63a	2.43a
	2.5, variable	4.21a	2.62a
Sandy Clay Loam	2.0, standard	4.35a	3.06a
	2.0, variable	3.52a	2.83a
Loamy Sand	2.0, standard	4.73a	2.45a
	1.5, variable	4.13a	3.05a

<sup>1</sup>Data were square root transformed before statistical analysis.

<sup>2</sup>Means followed by the same letter in each column are not significantly different at P=0.05 according to analysis of variance and the Fisher's LSD means separation test.

<sup>3</sup>Days after germination

Balan® was applied either at a standard rate or variably and in response to soil conditions (2.5 – 1.5 lb ai/acre) in lengthwise strips (600 x 60 ft) across the field. Each strip (six for each variable-rate and standard rate treatments) represented one replication in the experiment's randomized complete block design. Variable rate, site-specific herbicide applications were made using a 2004, SpraCoupe® (model 4640) integrated with Trimble® GPS guidance technology and a Raven Viper® flow control module. Two key components in this variable rate technology spraying system are the vehicle ground speed sensor and the CAN-bus (Controller-Area Network) hardware that includes: a) a boom control node that regulates the operation of the sprayer in sections (booms) through the interface with the operator and a switch box; and b) a CAN control node which receives information from pressure and flow meter sensors and then sends a signal to the flow control valve.

Application rates were adjusted by a variable rate controller, which incorporated an embedded computer that read sensor inputs, the GIS prescription map, user commands, and ground speed to calculate the correct application rate through an appropriate algorithm. The correct rate was then translated into actual product output through actuators, via opening/closing of solenoid valves and changes in rotational speed of hydraulic motors driving the pumps. Numerous variable rate controllers are available commercially which can interface with different devices through standard connectors. An important consideration when selecting a variable rate control system is the response times of its various components, because a rapidly responding system is needed to make the quick rate changes while moving from different application zones. Our system incorporated an automatic "look ahead" feature capable of providing the predictive speed compensation required to correctly synchronize product rates with the correct zones after subtracting inherent system lag times.

Following disc incorporation of Balan® to a depth of four to six inches, rows were listed on 42 inch centers and shaped to a height of ten inches. Green and ruby red leaf lettuce (*Lactuca sativa* var. *crispa*) was planted two-weeks following herbicide

application at two seed-lines per bed and germinated using sprinkler irrigation. Flood irrigation (~12 inches) was used to irrigate the crop to harvest. Three weeks after germination, seedling injury assessment was determined by counting plants within each soil textural class which showed stunting and a leathery leaf appearance, similar to those described by Tickes and Kerns (1996). All injured lettuce seedlings and weeds within an area measuring 75 ft. x 15 ft. in each plot were counted. Herbicide efficacy was determined by counting the number of weeds in each plot at 14 and 28 days after germination, and weed control was similar in all treatments (Table 2). Weed species controlled during the study included pigweed (*Amaranthus* sp.), purslane (*Portulaca oleracea*), lambsquarters (*Chenopodium album*) and groundcherry (*Physalis wrightii*). Treatment effects were also determined at lettuce maturity by counting unharvested lettuce heads within each experimental plot. All original observations were square root transformed prior to statistical analyses using SAS (Statistical Analysis System Institute, Inc.) software. Fisher's LSD means separation tests (P=0.10) were used to determine if weed control efficacy, lettuce injury and crop yield loss was significantly affected by herbicide treatment within each soil textural class.

## Case Study Results

Site-specific placement of Balan® in a field with non-uniform soil textures resulted in no significant differences in weed control efficacy as compared to the standard application rate (Table 2). Use of variable rate application technology however, significantly reduced levels of seedling injury by 30% in regions of our experimental field where soil texture was classified as light or sandy and application rates were 35% lower than the standard rate (Fig. 3). The crop injury effects were visually striking at four weeks after planting (Fig. 4). Reduced leaf lettuce injury also resulted in more uniform crop growth and consequently, increased yields of marketable lettuce of up to 40% at harvest. In loamy sand and sandy clay loam textured soils, the quantity of unmarketable lettuce was reduced by approximately 2,000 and 750 heads per acre, respectively (Fig. 5).



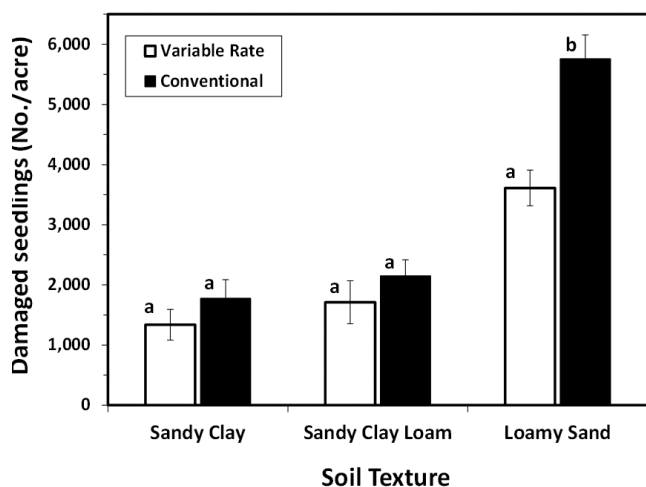


Figure 3. Variable rate Balan® applications reduce lettuce seedling injury when compared to standard application rate in sandy clay, sandy clay loam, and loamy sand textured soils. Means followed by the same letter within a soil texture are not significantly different according to a Fisher's LSD means separation test ( $P=0.10$ ). Data were square root transformed before statistical analysis.

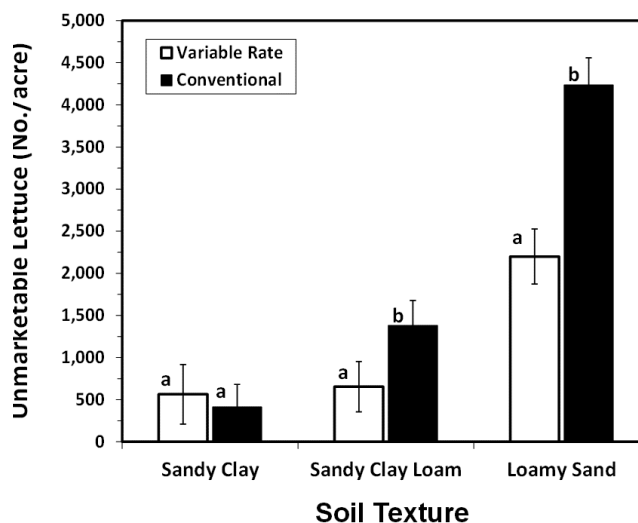


Figure 5. Unmarketable leaf lettuce heads grown in sandy clay, sandy clay loam, and loamy sand textured soils with standard and variable rate applications of Balan®. Means followed by the same letter within a soil texture are not significantly different according to a Fisher's LSD means separation test ( $P=0.10$ ). Data were square root transformed before statistical analysis.

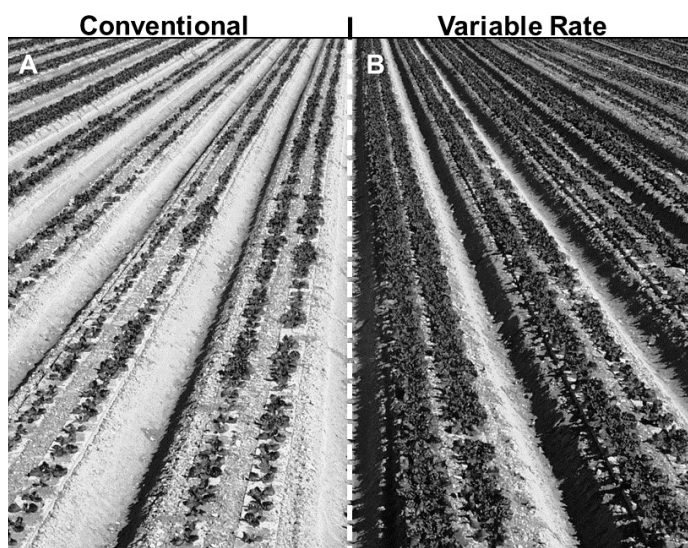


Figure 4. Ruby red leaf lettuce seedling injury (stunting) resulting from application of Balan® herbicide using standard (A) and variable (B) application schemes in loamy sand textured soil.

## Summary

The interaction between herbicide chemistry and soil properties greatly affects herbicide weed control efficacy and the potential for crop injury. Because of this, fields with significant variability in soil properties are good candidates for variable-rate application of soil-applied herbicides. A study conducted on a twenty acre commercial field near Yuma, AZ showed that use of variable rate technology with the herbicide Balan® resulted in significantly less crop injury and significantly more marketable yield as compared to uniform application. In the portions of the lettuce field with loamy sand textured soils, 35% less herbicide was applied and up to 40% more heads were harvested, which saved the grower approximately \$13/ac and increased gross revenues by over \$1500/ac. Furthermore, there were no significant differences

in weed control efficacy found between the two application methods examined. In summary, this project shows the potential for using variable rate technologies in vegetable production to apply preemergence herbicides.

Although these technologies have been used commercially to apply fertilizers for over a decade, they are just now being explored for use with preemergence herbicides in vegetables. While precision application approaches have the potential to lower production costs and improve farm profitability, the actual level of savings realized will vary from field to field depending on the degree of spatial variability, costs associated with sampling, and the capital investment for technology and equipment (English et al., 2001). Future studies should address the specific costs of implementing this technology, as well as including more variable inputs. Also, a thorough risk analysis would be beneficial in future explorations. However as researchers, manufacturers and growers learn more about precision management approaches, the productivity and cost savings gains of these technologies can only be expected to improve.

Precision herbicide management is an effective tool for spatial application of soil-incorporated herbicides which have

### Potential benefits of site-specific herbicide management include:

- Lower herbicide input costs resulting in higher net return on herbicide applications
- Reduced crop injury from over application of herbicides on lighter soil textures
- Better weed control when higher or lower rates are needed
- Reduced exposure of chemicals to environmentally sensitive areas where herbicides may cause ecological damage

a tendency for soil adherence. Although field implementation depends on previous knowledge of soil textural variability (soil test and texture evaluations), site-specific technologies show promise for Arizona vegetable fields with non-uniform soils. Regardless of the method used for textural characterization, growers should keep in mind that textural differences do not change in the short/medium term, so the costs associated with defining texture-based management zones can be spread over many years.

## References

- Bauer, W.D. and M. Schefcik. 1994. Using differential GPS to improve crop yields. *GPS World* 5(2): 38-41.
- Carlson, W.C., E.M. Lignowski and H.J. Hopen. 1975. Uptake, Translocation, and Adsorption of Pronamide. *Weed Sci.* 23(2):148-154.
- English, B.C., Roberts, R.K., and Mahajanashetti, S.B. 2001. Assessing Spatial Break-Even Variability in Fields with Two or More Management Zones. *J. Ag. Appl. Econ.* 33(3):551-565.
- Jacques, G.L. and R.G. Harvey. 1979. Adsorption and Diffusion of Dinitroaniline Herbicides in Soils. *Weed Sci.* 27(4):450-455.
- Koch, B. and R. Khosla. 2007. The Role of Precision Agriculture in Cropping Systems. *J. Crop Prod.* 9: 361-381. URL: [http://classes.css.wsu.edu/css403/8\\_PrecisionAg.pdf](http://classes.css.wsu.edu/css403/8_PrecisionAg.pdf).
- Moomaw, R.S., R.N. Klein, A.R. Martin, F.W. Roeth, P.J. Shea, G.A. Wicks and R.G. Wilson. 1992. Factors That Affect Soil-Applied Herbicides. University of Nebraska, Institute of Agriculture and Natural Resources, Cooperative Extension Service, Publication No.: G92-1081-A. URL: <http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=2219&context=extensionhist>.
- Peacock, B. 1998. The Use of Soil and Water Analysis. University of California Cooperative Extension. Publ. No. IG3-96. URL: <http://cetulare.ucdavis.edu/pubgrape/ig396.htm>.
- Tickes, B.R. and D.L. Kerns. 1996. Lettuce Injury from Preplant and Herbicides. IPM Series 9. Publ. No. 196007. University of Arizona, College of Agriculture and Life Sciences, Cooperative Extension, Tucson, Arizona. 4 pp. URL: <http://valueaddedag.org/crops/vegetables/weeds/lettuceinjury.html>.
- Weber, J.B. 1990. Behavior of Dinitroaniline Herbicides in Soils. *Weed Tech.* 4(2):394-406.
- Weber, J.B., G.G. Wilkerson, H.M. Linker, J.W. Wilcut, R.B. Leidy, S. Senseman, W.W. Witt, M. Barrett, W.K. Vencill, D.R. Shaw, T.C. Mueller, D.K. Miller, B.J. Brecke, R.E. Talbert and T.F. Peeper. 2000. A Proposal to Standardize Soil/Solution Herbicide Distribution Coefficients. *Weed Sci.* 48:75-88.
- Weed Science Society of America (2007). *Herbicide Handbook*, 9<sup>th</sup> edition. Lawrence, KS; Allen Press.



**THE UNIVERSITY OF ARIZONA**  
**COLLEGE OF AGRICULTURE AND LIFE SCIENCES**  
**TUCSON, ARIZONA 85721**

### KURT D. NOLTE

*Yuma County Cooperative Extension, University of Arizona, Yuma, AZ*

### MARK. C. SIEMENS

*Department of Agricultural and Biosystems Engineering, Yuma Agricultural Center, University of Arizona, Yuma, AZ*

### PEDRO ANDRADE-SANCHEZ

*Department of Agricultural and Biosystems Engineering, Maricopa Agricultural Center, University of Arizona, Maricopa, AZ*

### CONTACT:

**PEDRO ANDRADE-SANCHEZ**  
[pandrade@ag.arizona.edu](mailto:pandrade@ag.arizona.edu)

**This information has been reviewed by University faculty.**  
[cals.arizona.edu/pubs/crops/az1538.pdf](http://cals.arizona.edu/pubs/crops/az1538.pdf)

**Other titles from Arizona Cooperative Extension can be found at:**  
[cals.arizona.edu/pubs](http://cals.arizona.edu/pubs)

---

*Any products, services or organizations that are mentioned, shown or indirectly implied in this publication do not imply endorsement by The University of Arizona.*

---

Issued in furtherance of Cooperative Extension work, acts of May 8 and June 30, 1914, in cooperation with the U.S. Department of Agriculture, James A. Christenson, Director, Cooperative Extension, College of Agriculture & Life Sciences, The University of Arizona.

The University of Arizona is an equal opportunity, affirmative action institution. The University does not discriminate on the basis of race, color, religion, sex, national origin, age, disability, veteran status, or sexual orientation in its programs and activities.