Seed Productivity Research:
Precision Control of Tuber Size Distribution

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INTRODUCTION

A major research effort is underway in our lab to develop techniques to predict, manipulate, and better manage the physiological age and yield potential of seed potatoes. From a commercial production standpoint, the key questions are: How do we quantify the overall yield potential of a seed crop at harvest… or how can we assess tuber setting potential (i.e. potential productivity) before planting? Then if we can do this, how do we manipulate either physiological age (prior to planting) or agronomic management (after planting) so that tuber set and size development can be controlled within an optimum range for a particular market? Knowing the relative age and productive potential of a seedlot would allow for an adjustment of management practices to optimize yield and grade from that seed, given the climatic constraints of a particular growing region. Research support from the Washington State Potato Commission has enabled us to make good progress in addressing these questions.

OBJECTIVES

The objectives of the ongoing project are to:

- Develop procedures to predict the relative yield potentials of different seedlots in the Columbia Basin of WA.
- Determine the extent to which the predicted yield outcomes of seedlots can be altered (in relation to market requirements) by manipulating in-season management practices.

To accomplish these objectives, Ranger, Umatilla Russet and Russet Burbank seed-tubers were acquired at harvest from northern (54^{o}N latitude – Alberta Canada) and southern (47^{o}N latitude – Washington & Montana) growing regions. The seed-tubers were stored under different temperature regimes over a 200-day storage period to create seven physiological ages with different productive potentials. Seed was analyzed at planting to identify biochemical markers of age. The relationships among seed biochemical markers, stem numbers, tuber set, final yield and grade were then modeled extensively, resulting in a program that growers and consultants can use to estimate the relative productivity of seed prior to planting (from seed biochemical markers), or an established crop prior to row closure (from stem numbers). A brief summary of our results over the past four years appears below.

RESULTS

Effects of Seed Source on Productivity in the Columbia Basin

Regardless of cultivar, plant emergence from the youngest age of southern-grown Ranger (RR) and Russet Burbank (RB) seed was faster than that from northern seed (Table 1), reflecting a physiological difference attributable to growing region. Seed source affected the yield profiles (tuber size distribution) but, contrary to 'Northern Vigor' claims, had no effects on total and U.S. No. 1 yields, which averaged 32.3 and 26.4 T/A, respectively, for RB, and 32.7 and 28.6 T/A, respectively, for RR. In fact, southern-grown RB seed produced a 9.3% (2.7 T/A) greater marketable (U.S. no. 1 + undersize) yield than the northern-grown seed.

For both cultivars, plants from southern-grown seed set more tubers per hill than those from northern seed, resulting in a greater number of smaller U.S. No. 1 tubers per acre from the southern seed (Table 1). Specifically, 22 to 30% of the U.S. No. 1 yield of plants from northern seed consisted of oversize (>14 oz) tubers. In contrast, only 16 to 21% of the U.S. No. 1 tuber yield from southern-grown seed consisted of >14 oz tubers and a correspondingly higher percentage fell into the 4- to 14-oz size range compared with northern seed.

The tendency of northern seed to produce higher yields of larger-size tubers was at least partly due to lower average mainstem numbers and fewer tubers set per plant (Table 1). This, in turn, allowed for greater tuber size development. Similar to Ranger, northern-grown Russet Burbank seed behaved as physiologically younger seed relative to southern-grown seed. While seed-source did not affect total and U.S. #1 yields, tuber size distribution was altered significantly. Hence, northern- and southern-grown Ranger and Russet Burbank seed produce different yield profiles in the Columbia Basin. This knowledge provides an opportunity to customize in-season management practices to the seed source, in order to achieve maximum productivity with respect to market requirements for tuber size.

Stem Number, Tuber Set & Yield Relationships

For all cultivars and seed sources, stem numbers increased with storage degree-days (above 39oF) and temperatures (aging treatments), providing an ideal opportunity to model stem number/tuber set relationships. Figure 1 shows that the number of tubers per stem decreases with increasing stem number for each of the cultivars. Note that, at any given number of stems per plant, Umatilla Russet typically sets more tubers per stem than Ranger and Russet Burbank (top three graphs). This results in a greater number of tubers per plant for Umatilla than for Russet Burbank and Ranger Russet (2nd row of graphs), which in turn results in smaller average size tubers for Umatilla over the entire range of stem numbers (3rd row of graphs).

The relevance of these trends to controlling tuber size distribution in relation to market needs is seen in the tradeoff between average tuber weight and number of tubers per plant (bottom graphs). Regardless of cultivar, the greater was the number of tubers per plant, and the lower the average tuber weight. Note that Ranger tends to set fewer tubers per plant, Russet Burbank is intermediate, and Umatilla Russet sets the most tubers per plant, resulting in an opposite ranking of the cultivars for average tuber size (Ranger>Burbank>Umatilla). Interestingly, these changes in tuber set and size development occurred with little effect on total and marketable (U.S. #1 + <4-oz) tuber yields, except when stem number exceeded about 5.6 stems per plant for Umatilla (Figure 2).

These stem number/tuber set relationships provide the basis for estimating tuber size distribution and yield from aboveground mainstems early in the season. A high degree of correlation between stem numbers and yield of each of six tuber size classes further led to the development of prediction models (algorithms) to estimate entire yield profiles for all three cultivars (see Ranger example in Table 2). End-of-season yield profiles, defined by <4 oz, 4-6 oz, 6-10 oz, 10-12 oz, 12-14 oz , >14 oz, and total marketable tuber yields, can be estimated from stem numbers for northern- and southern-grown seed of each cultivar with the program provided on our website, www.ionophore.com/seed (Fig. 3). The yield profile calculator was recently updated to include all of the data collected during the 4-year project. Instructions on how to measure stem numbers, along with limitations of the calculator for estimating yield and grade profiles from different seed sources and cultivars, are also provided on the website.

Relative yield profiles for two or more crops (e.g. derived from different seedlots) grown in close proximity under the same management conditions in the Central Columbia Basin can be estimated from stem numbers measured just prior to row closure (e.g. early June).

Such estimates of yield potential early in the season provide an opportunity to adjust management practices through the remainder of the season, to optimize yield and tuber size distribution in relation to market needs. We are continuously updating this website with additional data as it emerges from the study.

In summary, the relationships among stem numbers, tuber set and size development have been modeled for processing cultivars in the Columbia Basin, to the extent that tuber size distribution and thus yield profiles can be estimated based on early-season stem counts. We also know how to age seed during storage to give a particular stem number. Hence, we are rapidly approaching the point where seed performance can be 'customized' through storage management to fit a particular market niche in terms of the desired tuber size profile. What is lacking, however, is a method to estimate the relative productive potentials of different seedlots prior to planting. Such a method would require a seed-based biochemical marker of productivity.

Biochemical Marker of Stem Numbers

A potential marker of tuber age and productivity may be 2-methyl-1-butanol. The level of this compound was higher in seed aged at higher temperatures during storage, and correlated well with stem numbers (and thus tuber set and yield) from the different ages of Ranger (e.g. Fig. 4) and Russet Burbank seed. Hence, seed butanol content predicts the average stem number per seedpiece prior to planting; from which the potential yield profile for a particular seedlot can be estimated (as in Table 2 and from our website, Fig. 3).

Managing Predicted Yield Outcomes

The next phase of this research focuses on the extent to which predicted yield outcomes can be modified through adjusting management practices, such as in-row spacing. A preliminary study using northern-grown RR seed was conducted in 2004. The stem numbers for two seedlots of RR were estimated from butanol levels at the end of storage. Butanol analysis predicted 2.3 and 5.3 stems/seedpiece for the seedlots (Fig. 4), which was slightly below the actual stem numbers of 2.9 and 5.9 measured 55 days after planting. The two seedlots were planted at 6-, 10- and 14-inch in-row spacings to determine the extent to which the predicted yield profiles (tuber size distributions) could be shifted.

Both seedlots increased the number of tubers/plant and decreased the number of tubers/A as in-row spacing increased. However, at 14-inch spacing, the 5.9-stem seedlot produced 61,000 more tubers/A than the 2.9-stem seedlot planted at the conventional 10-inch spacing (233,000 vs. 172,000 tubers/A). Hence, planting a high stem number seedlot at wider spacing to increase average tuber size did not negatively impact tuber number per acre. Average tuber size increased from 5.1 to 6.4 oz/tuber and the percentage of undersize (<4 oz) tubers decreased from 24% to 14% as spacing increased from 6 to 14 inches for the 5.9-stem seedlot. In-row spacing had no effect on marketable yield. Planting a high stem number seedlot at wider in-row spacing is thus an effective technique to increase average tuber size without sacrificing tubers/A.
Over 44% of the marketable yield from the 2.9-stem seedlot was oversize (>14 oz) at 10-inch spacing, resulting in high average tuber size (9.1 oz/tuber).

This agrees with our past studies that show that northern-grown RR seedlots have a tendency to produce a high proportion of oversize tubers in the Columbia Basin. At 6-inch spacing however, average tuber size of the 2.9-stem seedlot fell to 7.9 oz/tuber, the percentage oversize fell to 20%, and the tuber size profile was vastly improved. In addition, there was a 6 T/A increase in marketable yield at the 6-inch spacing compared with the 10-inch spacing. Closer in-row spacing for low stem number seedlots of northern-grown RR seed is an effective technique to reduce the percentage oversize and thus optimize tuber size distribution. These studies are the first to demonstrate that the predicted yield profiles at the beginning of the season (based on butanol analysis of seed before planting) can be altered by manipulation of in-row spacing to achieve a more desirable tuber size distribution.

Control of Tuber Size Distribution in Russet Norkotah

We are also modeling stem number/tuber set relationships for Russet Norkotah strains, so that tuber size profiles can be controlled with greater precision for the fresh market. It is well documented that the CO Norkotah selections 3 and 8 (CORN 3, CORN 8) are more nutrient efficient than standard Norkotah, producing anywhere from 2.5 to 5 T/A higher yields with 100 lbs/A less nitrogen over the course of a growing season. There is thus an economic advantage to growing these selections relative to standard Norkotah.

In 2004, we compared the yields of these selections to that of standard Norkotah at nitrogen levels recommended for the latter. Relative to standard Norkotah, there was a 7 T/A (22%) and 14 T/A (46%) advantage in the marketable yields of CORN 8 and 3, respectively, at this nitrogen level (Table 3). The 14 T/A higher yield of CORN 3 versus standard Norkotah (45.2 vs. 30.9 T/A) was at least partly due to the relatively high nitrogen level. CORN 3 averaged 9.0-oz tubers versus 5.6-oz tubers for standard Norkotah (a 61% difference). However, nearly 40% of the marketable yield of CORN 3 was comprised of oversize (>14 oz) tubers, which are less desirable for the fresh market. We therefore determined the extent to which the yield profile of CORN 3 could be shifted away from oversize tubers toward higher yields of tubers in the more desirable size classes (e.g. 6 to 12 oz) by manipulating stem numbers.

As the average stem number of a seedlot increased from 2.3 to 4.8, average tuber size decreased from 9.4 to 6.1 oz/tuber (Table 4). This occurred with a substantial increase in the number of tubers set per plant (from 8.3 to 12.0) and per acre. Additionally, the yield of oversize tubers fell from 40 to 8% of marketable yield, while the yield of 6- to 10-oz tubers increased from 22 to 40%, as stem numbers increased from 2.3 to 4.8. The marketable yield did not change with increasing stem numbers (avg 42.5 T/A). We were thus able to shift the tuber size distribution of CORN 3, while still maintaining the tremendous yield advantage over standard Norkotah, when both were grown at the same level of nitrogen nutrition. Manipulating stem numbers appears to be a very effective technique for changing the yield profiles (tuber size distribution) of the Norkotah selections. We will be adding stem number, tuber set and size distribution models for the Norkotah selections to our seed productivity website following the 2005 growing season.

Summary

An ideal tuber age exists for every production region and market niche, where tuber set and size development can be optimized for maximum economic return. The challenges are to accurately estimate the productive potentials prior to or shortly after planting so that management practices can be adjusted to optimize yield profiles and satisfy market requirements for tuber size. In the future, seed growers may be able to add value to their crops by manipulating the productive potentials of seed to more closely match the varying requirements of different markets (e.g. seed, fresh, processing).

Our research has demonstrated that:

- Aging seed in storage affects the productivity of Russet Burbank, Ranger Russet and Umatilla Russet seed-tubers primarily by altering stem number/tuber set relationships, resulting in substantial shifts in tuber size distribution.
- Within limits, manipulating seed storage temperature can effectively change tuber size distribution to meet market requirements without affecting total, U.S. #1 or marketable yields under Columbia Basin growing conditions.
- Umatilla was the most sensitive to aging treatments for a shift in tuber size distribution and a decline in productivity, followed by Ranger and Russet Burbank. This underscores the need for good temperature management of Umatilla seed after harvest.'Northern vigor' was nonexistent in Russet Burbank and Ranger seed (total, and U.S. No. 1 yields were equivalent for northern and southern seed). However, the size distribution of U.S. No. 1 and marketable tubers was affected by seed source; northern seed produced more oversize (>14 oz) tubers than southern seed.
- Tuber set and size development can be predicted from early-season stem counts for Russet Burbank, Ranger and Umatilla Russet potatoes, providing an opportunity to adjust management practices to optimize yield for a particular market.
- Seed butanol concentration increases with heat-unit accumulation by seed in storage and correlates with stem numbers in Ranger Russet and Russet Burbank seed, providing a marker for the relative productivity of different ages of seed-tubers prior to planting.
- Predicted yield profiles for seedlots at the beginning of the season can be modified by varying in-row spacing to optimize tuber size distribution in relation to market requirements.
- The tendency of the CORN selections to produce high yields of oversize tubers can be controlled, without losing the tremendous yield advantage over standard Norkotah, by manipulating the stem numbers of seedlots.

Table 1. Differences in productivity of the youngest age of northern- and southern-grown Russet Burbank and Ranger Russet seed in the Central Columbia Basin of WA. Seed-tubers were acquired at harvest, wound-healed at 54oF for 10 days and stored at 39oF for the remainder of the 200-day storage period. Data are averages of 3 and 4 years of field research for Ranger and Russet Burbank, respectively.

	Russet Burbank Seed Source		**Ranger Russet Seed Source**	
Yield Components	**North-ern**	**South-ern.**	**Northern**	**Southern**
% Plant Emerg. (28 DAP)[a]	42.2	85.1**	72.5	86.9**
Stem No./plant	3.2	3.7*	2.7	3.1*
Total Yld (T/A)	31.4	33.1 ns	33.2	32.2 ns
Mkt Yld (T/A)[b]	28.9	31.6*	31.9	31.5 ns
U.S. No. 1 (T/A)	25.8	27.0 ns	29.4	27.7 ns
< 4 oz (T/A)	3.10	4.63**	2.53	3.79**
4–6 oz (T/A)	4.68	6.90**	4.04	5.29**
6-10 oz (T/A)	9.16	10.8*	9.12	9.64 ns
10-12 oz (T/A)	3.50	2.98 ns	4.08	3.80 ns
12-14 oz (T/A)	2.55	1.90*	3.33	3.04 ns
> 14 oz (T/A)	5.76	4.38*	8.79	5.90**
Cull (T/A)	2.53	1.61*	1.29	0.75 ns
Tubers/plant	7.8	9.2**	7.0	7.9**
Ounces/tuber	7.14	6.29**	8.3	7.3**
Tubers/A	131,900	164,300	127,600	145,300**

[a]DAP, Days after planting. [b]Mkt Yld (marketable yield) = total yield minus culls. *,**P≤0.05 or 0.01, respectively, for comparisons between seed sources within a cultivar (ns, not significant).

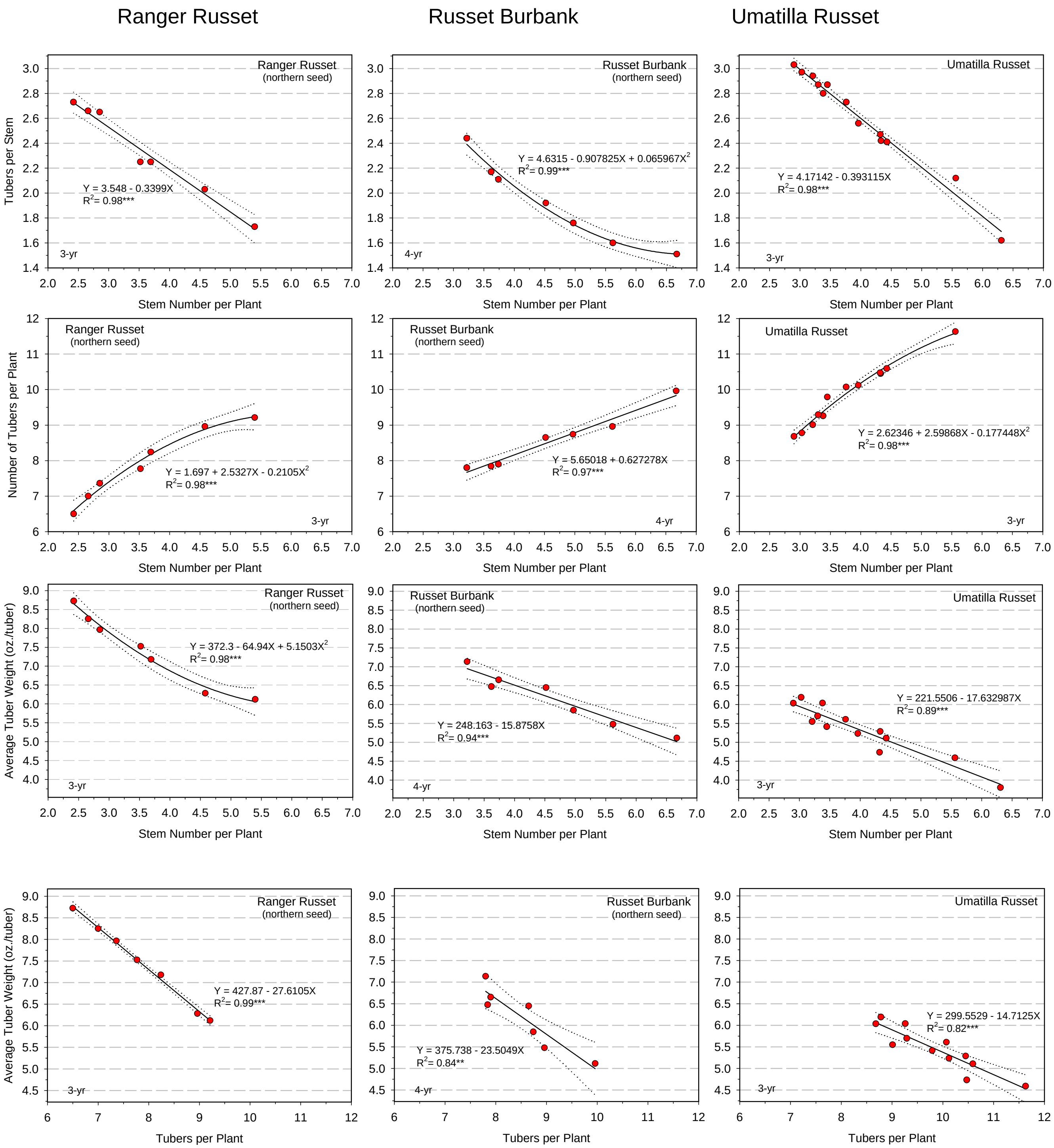

Figure 1. Stem number/tuber set relationships for Ranger Russet (left), Russet Burbank (middle) and Umatilla Russet (right) potatoes in the Central Columbia Basin. Data is averaged over 3 or 4 years as indicated. Line equations for average tuber weight are based on g/tuber. Dotted lines indicate 95% confidence intervals.

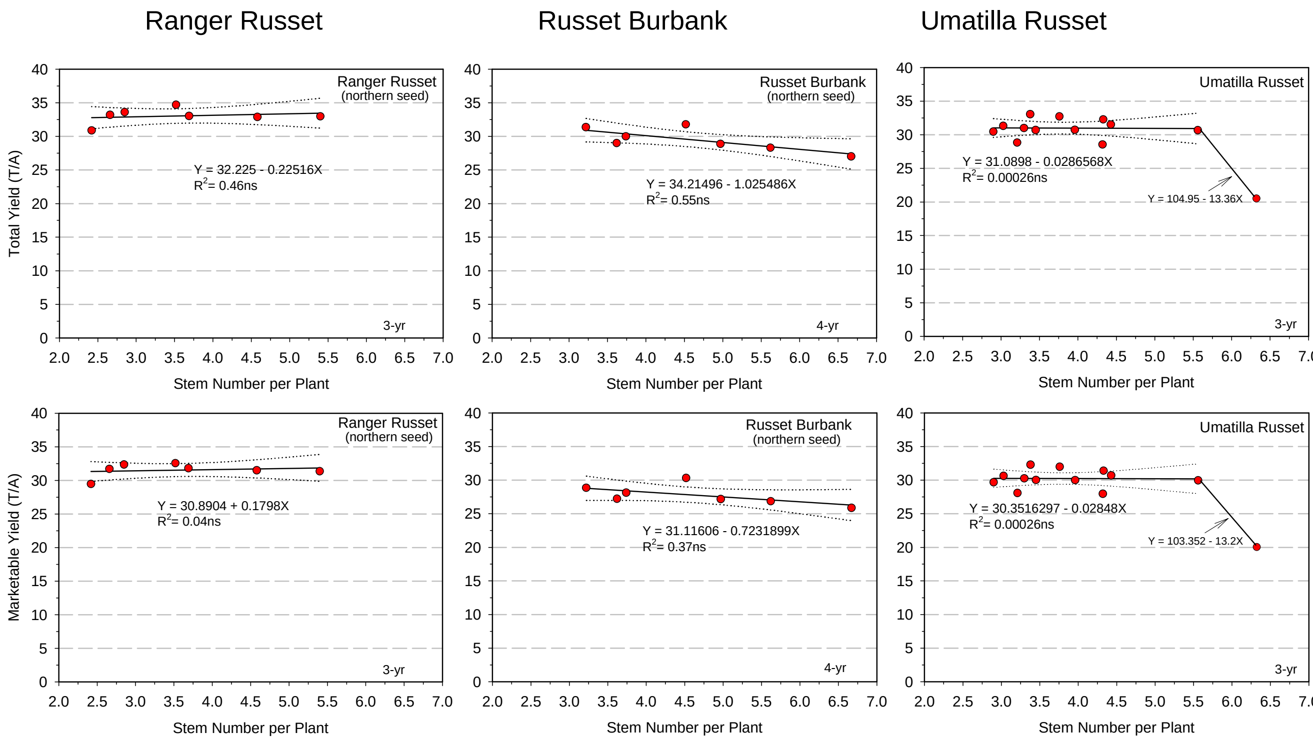

Figure 2. Effects of increasing stems per plant on total and marketable yields (U.S. #1 + undersize) of Ranger Russet (left), Russet Burbank (middle) and Umatilla Russet (right) potatoes in the Central Columbia Basin. Data are averaged over 3 or 4 years, as indicated. Dotted lines indicate 95% confidence intervals.

Table 2. Predicted changes in yield profile, tuber set and size with increasing aboveground stems from northern-grown Ranger Russet seed-tubers planted in the Columbia Basin (regression models upon which these estimates are based were derived from 3 years of field data, 2001-2003). This data can be generated from the seed productivity website (see Fig. 3).

	Mkt. Yld	**Percent of Marketable Yield – northern RR seed**						**Tuber No.**		**Tuber Wt.**		**Tubers/A**
Stems/ Plant	**(T/A)**	**< 4 oz**	**4-6 oz**	**6-10 oz**	**10-12 oz**	**12-14 oz**	**>14 oz**	**per stem**	**per plant**	**g/tuber**	**oz/tuber**	**(1000's)**
2.6	31.4	8.2	12.2	27.9	11.5	10.0	29.8	2.7	6.9	238.3	8.4	123.2
2.8	31.4	9.0	12.9	28.5	11.4	9.8	28.5	2.6	7.1	230.8	8.1	128.8
3.0	31.4	9.8	13.6	29.0	11.2	9.6	27.1	2.5	7.4	223.8	7.9	134.1
3.2	31.5	10.5	14.4	29.5	11.1	9.4	25.8	2.5	7.6	217.2	7.7	139.0
3.4	31.5	11.2	15.1	29.9	11.0	9.2	24.5	2.4	7.9	211.0	7.4	143.5
3.6	31.5	11.9	15.8	30.3	10.9	9.0	23.1	2.3	8.1	205.3	7.2	147.7
3.8	31.6	12.6	16.5	30.6	10.8	8.8	21.8	2.3	8.3	199.9	7.1	151.5
4.0	31.6	13.2	17.3	30.9	10.7	8.6	20.5	2.2	8.5	194.9	6.9	154.9
4.2	31.6	13.7	18.0	31.1	10.6	8.4	19.1	2.1	8.6	190.4	6.7	158.0
4.4	31.7	14.2	18.7	31.3	10.5	8.2	17.8	2.1	8.8	186.3	6.6	160.7
4.6	31.7	14.7	19.5	31.5	10.3	8.0	16.4	2.0	8.9	182.6	6.4	163.0
4.8	31.8	15.2	20.2	31.6	10.2	7.8	15.1	1.9	9.0	179.3	6.3	164.9
5.0	31.8	15.6	20.9	31.7	10.1	7.6	13.8	1.8	9.1	176.4	6.2	166.5
5.2	31.8	16.0	21.6	31.7	10.0	7.4	12.4	1.8	9.2	173.9	6.1	167.7
5.4	31.9	16.3	22.4	31.7	9.9	7.2	11.1	1.7	9.2	171.8	6.1	168.5
Coeff of det (R^2)[a]	0.04 ns	0.95***	0.99***	0.73*	0.29	0.78**	0.95***	0.98***	0.98***	0.98***	0.98***	0.98***
Std. Error of Est.[b]	-	0.9	0.4	1.2	-	0.6	1.8	0.06	0.16	4.4	0.15	3.6

[a]Values (x100) represent the percent variation explained by the models.

*,**,***Correlations were significant at the 0.05, 0.01 and 0.001 levels, respectively.

[b]Standard errors of the estimates of percent yield, tuber set and size from stem number per plant.

Figure 3. Website to illustrate the effects of seed source and stem numbers on tuber set and size distribution of Ranger Russet, Russet Burbank and Umatilla Russet seed potatoes in the Columbia Basin of Washington. Seed was acquired from northern and southern growing areas. Estimates of tuber set and size distribution from stem numbers are based on 4-year average yields from different physiological ages of seed tubers planted in replicated plots at Othello, WA. Spacing was 34 inches between rows and 10 inches between seedpieces (1.75-2.25-oz/seedpiece) within a row. Seedpieces were planted 8 inches deep. Stem number per plant inputs to the calculator should be the average over at least 100 ft of row. All crops were grown for an average of 160 days under a linear move irrigation system. The estimates of percentage tubers in each size category from stem numbers will vary with spacing. An example of the predicted changes in yield profile from northern-grown Ranger seed with increasing stem numbers (as estimated through this website) appears in Table 2. Access this website directly at www.ionophore.com/seed or indirectly through the postharvest variety development website (www.wsu.edu/~fullern) and click on "Seed Productivity Website"

- Select a cultivar and seed source: Russet Burbank Northern
- Enter seed butanol content (ng/g fresh weight): 250 calculate

  Your plants will have roughly 4.9 stems each

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	Stems Per Plant						
Yield Component	3.4	4.2	5.0	6.2			calculate
Less than 4 oz (%)*	11.3	13.7	16.8	22.5			
4oz - 6oz (%)	17.9	20.1	22.3	25.6			
6oz - 10oz (%)	33.0	33.5	33.2	31.6			
10oz - 12oz (%)	11.8	10.7	9.6	8.0			
12oz - 14oz (%)	8.1	7.2	6.2	4.8			
Greater than 14 oz (%)	17.6	14.7	11.8	7.5			
Tubers per stem	2.3	2.0	1.7	1.5			
Tubers per plant	7.8	8.3	8.8	9.5			
Grams per tuber	194.2	181.5	168.8	149.7			
Ounces per tuber	6.8	6.4	6.0	5.3			
Tubers per acre (x1000)	133.2	144.0	152.8	162.4			
Marketable yield (T/A)	28.7	28.1	27.5	26.6			

*% of marketable yield (4oz - 14oz plus < 4oz)

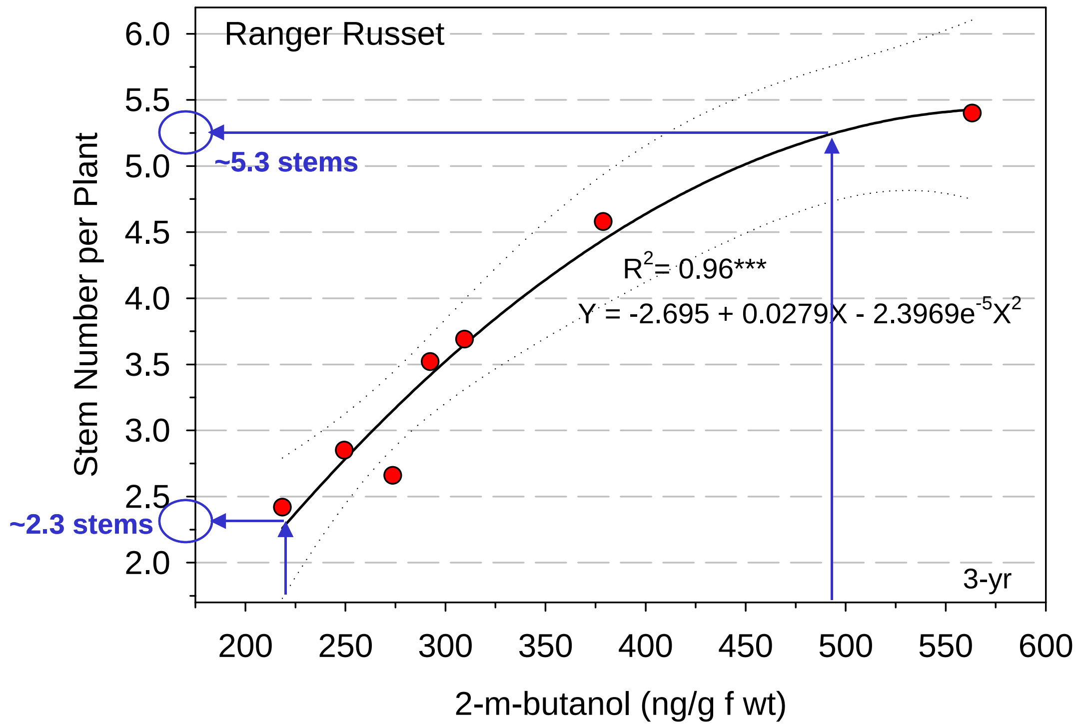

Figure 4. Relationship between 2-methyl-1-butanol content in Ranger Russet seed-tubers and aboveground mainstem numbers. Northern-grown seed-tubers were stored at different temperatures to produce a range of stem numbers (see Fig. 1). 2-m-butanol was measured at the end of the 200-day storage seasons, prior to planting. Stem numbers were counted in mid June, approximately 55 days after planting. Data are averaged over 3 years (2001-2003).

Table 3. Comparison of stem number, tuber set and yields of Norkotah selections grown at Othello, WA in 2004 (122 days after planting).

	Norkotah Selection		
	Std.	CO-3	CO-8
Stem No./plant	3.6	2.9*	3.1
Tubers/plant	9.8	9.1	10.2
Tubers/stem	2.7	3.2*	3.4*
oz./tuber	5.6	9.0**	6.6*
	Tuber Yields (T/A)		
Total	30.9	45.3**	37.7*
Marketable	30.9	45.2**	37.7*
U.S.#1	25.0	43.2**	33.3*

*,** Selections were significantly different from standard Norkotah at P[0.05 and 0.01, respectively

Table 4. Effects of aboveground stem numbers on various yield components produced by CO Russet Norkotah selection 3 (CORN 3) at Othello, WA during 2004.

CORN 3 Yield Components	**Average Aboveground Stem No. (per seedpiece)**		
	2.3	3.3	4.8
Mkt Yield (T/A)	43.8	42.4	41.2
Tubers/plant	8.3a	9.4b	12.0c
Tubers/A	147,600a	172,200b	217,000c
oz/tuber	9.4a	7.9b	6.1c

For a particular yield component, numbers followed by different letters are significantly different at P≤0.05.