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# Development of irrigation best management practices for potato from a research perspective in the United States (1)

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***Abstract***
Irrigation in the era of "best management practices" requires the simultaneous achievement of effective water use for profitable production and environmental protection. Irrigation in excess of crop use should be minimized due to the risk of leaching of nitrate and pesticide residues towards groundwater and the risk of runoff losses of sediment and nutrients to surface water. Excessive irrigation promotes potato diseases. Yet potato is a shallow rooted, water stress sensitive crop. Water deficits reduce tuber yields and quality. Tuber quality parameters that are influenced by water stress include tuber grade, specific gravity, heat necrosis, susceptibility to bruise, hollow heart, translucent-end, jelly end rot, and the dark color of fried strips and chips. Tuber grade, as determined by shape, smoothness, and freedom from visible defects such as growth cracks, dumbbells, and knobs, is highly sensitive to irrigation management deficiencies. Together these tuber responses to deficit irrigation make potato a challenging crop to irrigate. Research has developed techniques to determine ideal irrigation timing based on allowable soil water depletion (ASWD), soil water tension (SWT), and crop evapotranspiration (ETc). Irrigation amounts are based on soil water status or ETc. Sprinkler irrigation systems are generally superior to furrow systems for potato production. Drip irrigation systems are used in specialized production circumstances and are the subject of intensive research. Irrigation practices for potato have strong interactions with nutrient management, especially nitrogen rates and timings. Optimal irrigation management for potato crop is demanding, because both under and over irrigation have clear negative consequences.

***Keywords***
irrigation scheduling, *Solanum tuberosum* L., soil water tension, evapotranspiration, yield, quality, environmental protection.

## 1. Introduction

Best Management Practices, also known as "BMPs", are common-sense actions required by law to keep soil and other pollutants out of streams and lakes. BMPs are designed to protect water quality and to prevent new pollution.

BMP involves the proper management of irrigation applications to meet the water requirements of the crop without wasting water, soil, or nutrient resources. Irrigation water should be managed so that the water table depth is maintained 38 to 61 centimeters from the top of the potato row (Hutchinson et al., 2002).

Potatoes are often considered to be a high water use crop, when in fact many other crops grown in the Treasure Valley of Eastern Oregon and Western Idaho have equal or greater seasonal water use requirements. This misconception arises from the fact that potatoes are more sensitive to water stress compared to most other crops, have a relatively shallow root-zone depth and are often grown on soils with low to medium water holding capacities.

Irrigation in the era of BMPs requires the simultaneous achievement of effective water use for profitable production and environmental protection. Potato yield and grade are reduced by both over- and under-irrigation. A mere 10 percent deviation from optimum water application throughout the growing season may begin to decrease yield. This sensitivity to water management is

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attributable to the sensitivity of potato plants to water stress, coupled with very little buffering of the soil-plant system to water management errors resulting from limited soil water storage. Yield reductions due to over-irrigation can be ascribed to poor soil aeration, increased disease problems, and leaching of nitrogen from the shallow crop-root zone. Efficient irrigation management can increase marketable yield while reducing production costs by conserving water, energy, and nitrogen fertilizer, as well as scuppering potential ground water contamination.

## 2. Irrigation criteria

Irrigation of crops sensitive to water stress requires systematic scheduling of irrigation decisions. There are three methods for matching irrigation with crop water requirements. The first is to measure how much water the soil contains. The second is to monitor some attribute of the plant that is related to water deficits, such as canopy temperature, xylem water potential, and visible wilting. The third is to calculate how much water the atmosphere can extract from a well-watered crop. Examples of the latter irrigation criterion are weather forecasts made by AgriMet, estimates of reference (ETo) and crop evapotranspiration (ETc), pan evaporation and atmometers measurements. AgriMet is an automated agricultural weather station network operating throughout the Pacific Northwest of the USA that uses site-specific climatic data, the current stage of growth of local crops, and crop models to estimate daily crop water use. Access to daily weather data, crop water use charts, and related information is available over the Internet at http://www.usbr.gov/pn/agrimet.

Soil-based irrigation scheduling methods range from the simple "feel" method to such technologically advanced methods as the neutron probe and time-domain reflectometry (Campbell and Mulla, 1990; Shock, 1998). Tensiometers and gypsum blocks provide technology and cost between these extremes, but they have limitations for practical use by growers. Tensiometers require continual service, skill in installation and management, and only measure in the 0 to 70 kPa range of soil water tension with a reduced range in coarse-textured soils (Cassel and Klute, 1986). The water content of gypsum blocks, or any porous absorber placed in firm contact with soil, depends on the soil water tension and not the water content of the soil (Gardner, 1986). Gypsum blocks are manufactured at different sensitivities by mixing the plaster to obtain different ranges of pore sizes (Campbell and Gee, 1986). Gypsum blocks slowly dissolve, may lose firm contact with the soil, and may respond inconsistently to soil moisture changes. Wetting and drying response of gypsum blocks can have troublesome time lags. Because of these limitations, tensiometers and gypsum blocks have not gained wider acceptance for irrigation management.

A granular matrix sensor (GMS) for electronically measuring soil moisture was patented by Larson (1985) and is marketed as the "Watermark" soil moisture sensor by Irrometer Co. of Riverside, California. GMS technology reduces the problems inherent in gypsum blocks of inconsistent pore size distribution and loss of contact with the soil by dissolving, by use of an insoluble granular fill material held in a fabric tube supported in a metal or plastic screen (Shock et al., 1996; Shock, 2003). GMS operate on the principle of electrical resistance and the electrodes inside the GMS are imbedded in a second chamber of the granular fill material above the gypsum wafer. The gypsum wafer provides a buffer to the effects of salinity of the soil solution on electrical resistance between the GMS electrodes. According to Larson (1985), particle size of the granular fill material and its compression determines the pore size distribution in the GMS and its response characteristics. Alternative sensor designs have been proven effective (Shock et al. 1998c).

GMS calibration using a pressure plate apparatus was described by Thomson and Armstrong (1986) and using tensiometers in the field by Eldredge et al. (1993). Shock et al. (1998c) related GMS readings to soil water tension in a weighing lysimeter and developed calibration equations

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including temperature compensation for variable GMS design. These calibrations have been used for hand held digital meters and data loggers - the AM400 (MK Hansen Co.) and the Watermark Monitor (Irrometer Co., Inc.) (Shock and Shock, 2004). Drip irrigation test plots at the Malheur Experiment Station (MES) have been automated since 1995 with the use of GMS and other sensors (Shock et al., 2002c).

Tensiometers, gypsum blocks and GMS sensors were designed to measure soil water tension (SWT), also known as soil water potential. SWT is the force necessary for the roots of the plants to extract water from the soil matrix, and reflects the exact moment at which irrigation should start to guarantee higher crop yields and better quality. When the soil is wet, little force is needed; as it dries out more force or suction is needed. For the purposes of irrigation, the water status of the soil is usually expressed as the volume of water in a given volume of soil, which in turn is intimately related to SWT.

The critical values of SWT are extremely dependent on the crop, soil texture, and local climatic conditions. Based on potato yield and grade responses to irrigation, ideal potato SWT irrigation criteria in the USA were found to be 50 kPa using furrow irrigation on loam in California (Timm and Flockner, 1966), 50 to 60 kPa using sprinklers on silt loam in Oregon (Eldredge et al., 1992, 1996), 25 kPa using sprinklers on silt loam in Maine (Epstein and Grant, 1973), 60 kPa and 30 kPa using furrow and drip irrigation systems, respectively for silt loam in Oregon (Shock et al., 1993a, 2002a), and 20 kPa using sprinklers on sandy loam in western Australia (Hegney and Hoffman, 1997).

## 3. Water management in potato production systems

Crop consumptive water use is the amount of water transpired by the plants plus the water evaporated from the soil plus the fraction of water held by the plant tissues. The amount of water retained by the plant metabolic activity is about 1% of the overall water taken up by the plants. Thus, in practical terms crop water consumption corresponds to crop maximum evapotranspiration (ETc), which included the evaporation e.g. from the soil surface. Potato ETc can be estimated using weather data and is the amount of water to be replenished during the growing season in order to assure potential tuber yields at a given site. Potato ETc is important to consider in irrigation planning and its use in irrigation scheduling is a well-developed strategy to improve the effectiveness of irrigation.

Evapotranspiration varies according to meteorological conditions, plant and soil surface wetness, crop type, soil water status, and amount of crop cover (LAI – leaf area index). The mainly meteorological parameters that affect ETc are solar radiation, relative humidity, ambient air temperature and wind speed. Since these climatic elements can vary considerable from day-to-day, so will ETc. Furthermore, seasonal ETc will vary from year-to-year in response to annual meteorological trends at a given site.

Potato can be sensitive to irrigation less than ETc. Shock et al. (1998b) proposed a 3-year study on silt loam in eastern Oregon to examine the effect of water deficit on yield and quality of four potato cultivars. Application rates less than ETc in the Treasure Valley of Oregon affected crop yield and can not be adopted as a feasible irrigation scheduling strategy to economize water. This is because the small benefit eventually obtained by the grower with irrigation water amounts less than ETc would not counterbalance the high risk of reduced tuber yield and profit from water saving.

Potato ETc varies substantially from one site to another. For high yields, Doorenbos and Kassam (1979) reported that the seasonal potato water requirements for a phenological cycle varying from 120 to 150 days are within the range of 500 to 700 mm, depending on climate

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conditions. However, under the atmospheric conditions of Botucatu, State of Sao Paulo, Brazil during the winter, Pereira et al. (1995) obtained a seasonal potato ETc of 283 mm, and Tanner (1981) in the humid areas of Wisconsin area, USA, observed that ETc for a potato crop ranged from 293 to 405 mm during the summer time.

Wright and Stark (1990) reviewed potato water requirements. They tabulated water use reported by researchers for 17 potato irrigation experiments nationwide, and found that the total seasonal water requirement ranged from 450 to 700 mm. This water use requirement is lower than crops like corn (for grain) and alfalfa (for hay), which may require 900 to 1300 mm during the growing season for the same production areas.

Water and nitrogen are important factors influencing tuber growth, development, quality and yield. Balanced management of these two factors is important in a dry climate, as in the eastern part of the Pacific Northwest states, where rainfall during the growing season is extremely low and soils have low organic matter content. Compared to many other crop plants, potatoes close their stomata at relatively small soil moisture deficits. Thus, soil moisture stress influences various physiological activities affecting the tuber yield and quality. Potatoes have a shallow root system (Corey and Blake, 1953; Durrant et al, 1973; Fulton, 1970), which requires more frequent irrigation when compared to other crops. Extreme variations in irrigation management and nitrogen availability influence tuber yield, size, grade, external quality, and internal quality.

Because of the sensitivity of potatoes to water stress, most research has been focused on avoiding deficiencies in soil water. Tuber yield responses to irrigation decrease with over-irrigation (Hill, et al., 1985). Tuber market grade reduction at continuously wet soil water tension has been ascribed to inadequate soil aeration (Holder and Cary, 1984). Internal brown spot was found to increase with over-irrigation during early tuber development (Hiller and Koller, 1984).

Solomon (1984) pointed out that since no irrigation system is perfectly uniform, application uniformity should be quantified in order to measure irrigation system efficiency, because an irrigation must continue long enough to adequately water plants receiving the least water. The scale of the uniformity measurement should be related to the soil volume occupied by potato roots (Letey, 1985). Because potato is grown in hilled rows, there is a micro-topographic influence on water distribution uniformity. Saffigna et al. (1976) measured sprinkler water application to potato and found that water runs down stems and down the sides of the potato hill, saturating the soil in the center of the hill and below the furrows. Yoder et al. (1991) studied water movement in potato hill topography and found that most of the water applied by sprinklers ran off the hills and infiltrated below the furrows. In contrast, solid set sprinkler irrigation results in uniform wetting of potato hills at Ontario in silt loam (Steiber and Shock, 1995). The more uniform water distribution noted at Ontario, Oregon, which is not noted elsewhere, may be caused by better lateral transmission of water in these specific silt loams.

Since potato economic yield is so sensitive to soil water stress, there is a strong financial incentive for growers to simplify management by over-irrigating their potato crop. It appears that the general practice in irrigated potato production in the Treasure Valley, whether furrow or sprinkler irrigation is used, is to attempt to maximize the time between irrigations while minimizing plant water stress by uniformly saturating the crop root zone. Not all the water applied in a saturating irrigation is available to the plants, since some is lost to deep infiltration past the root zone and some water is lost to surface runoff. The crop survey by Jensen and Simko (1991) revealed that potato irrigation substantially exceeded potato crop evapotranspiration.

A few advantages of moderate early season water stress have been described. Verticillium wilt on potato is decreased by early season water stress (Powelson and Christensen, 1991). Tuber market grade and stem-end fry color is improved by moderate stress before tuber initiation (Shock et al., 1992).

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## 4. Drip irrigation in potato production systems

Up to 1998 drip irrigation had not been successfully utilized for potato production in the Pacific Northwest. Trials at the Malheur Experiment Station (MES), in southern Idaho, in the Hermiston-Boardman region, and at Yakima had failed to equal or surpass the yield and quality produced with sprinkler irrigation (Shock, et al., 1993a; personal communication with Howard Niebling, Brian Anderson, and Bart Nelson in 1998). Failures were associated with the use of the Russet Burbank variety and difficulties in drip tube placement. Deep drip tape placement resulted in yield and grade reduction, as would be anticipated due to poorer water supply to the shallow root system of potato. Shallow drip tape placement in heavy textured soils resulted in water savings, but also in difficulty to assure tuber quality because of soil saturation and subsequent soil adherence on the tubers.

Sammis (1980) compared sprinkler, surface drip, subsurface drip, and furrow irrigation for the production of potato and lettuce in New Mexico. Subsurface drip irrigation (SDI) with a 20-kPa irrigation criterion was among the most productive irrigation systems. Shae et al. (1999) studied four options for managing drip irrigation of potatoes in North Dakota. Automation of the irrigation based on a soil water tension irrigation criterion at 30kPa had relatively high water use efficiency. Smajstrla et al. (2000) compared automated controlled SDI irrigation with the conventional semi-closed seepage sub-irrigation in Florida. The conventional irrigation system is under criticism because of surface runoff and nutrient contamination of adjoining waterways. The SDI system required more electrical energy but used 36% less water to obtain the same potato yield. Steyn et al. (2000) examined irrigation-scheduling options for drip-irrigated potatoes.

For sprinkler-irrigated potato, extensive work has been done on potato responses to N fertilizer and N losses, but relatively few studies have studied potato N fertilization and loss under drip irrigation. Sprinkler irrigation at different irrigation criteria was compared to surface drip and buried drip irrigation (with a range of fertilization treatments), for potato yield and grade in Minnesota (Waddell et al., 2000). Less water was required using either drip irrigation system. Surface drip and buried drip were among the most productive systems for total and marketable yield. Furthermore, drip irrigation or sprinkler irrigation (at a relatively dry soil criteria) reduced nitrate leaching under potato compared to normal sprinkler irrigation (Waddell et al., 1999). Neibling and Brooks (1995) reported that reduced nitrogen rates did not affect potato yield, when irrigated with a subsurface drip system.

Simone et al. (2002) showed that drip irrigation had potential as an economically viable potato production method in the southeastern United States. Optimized irrigation rates were 99% to 86% of the water called for in their irrigation model. Zartman et al. (1992) examined tape depth and emitter spacing on tuber yield and grade of Norgold Russet potato in Lubbock, Texas. Tape depth or emitter spacing did not influence potato yield, but the proportion of misshaped tubers was greater when the tape was buried at 0.2 m than with shallower placement. Soil temperature was greater with the tape at 0.2 m than at 0.1 m or 0.025 m. DeTar et al. (1996) found that tape depths of 0.08 m (above the seed piece) and 0.46 m (below the seed piece) performed better than intermediate and greater depths.

Fabeiro et al. (2001) used 10 drip irrigation treatments to examine the effect of the timing of irrigation deficits on potato yield and water use efficiency in Spain. Irrigation deficits occurring during mid- and late-season tuber bulking were particularly damaging to yield. High yield was combined with high water use efficiency when irrigation deficits were restricted to early in the season. Shock et al. (2002a) investigated the performance of 'Umatilla Russet' under drip irrigation in silt loam. The factors considered in the study were tape placement (one tape per row or one tape per two rows) and four soil water tension levels for automatically starting irrigation (15, 30, 45, and 60 kPa). They concluded that drip tape placement had a significant effect on every

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variable except total marketable yield and bud-end fry color for which interactions of irrigation criteria with tape number were significant. Tape placement and irrigation criterion interacted to influence total yield, total marketable potatoes, and US No. 2 yield. Results indicated potato should be irrigated at 30 kPa, given the silt loam soil and 2.5 mm water applied at each irrigation episode. The irrigation criterion considered alone only influenced the total US No.1 and over-340-g tuber size categories. Potato cultivars were very different in their performance under drip irrigation (Eldredge et al., 2003).

## 5. Nitrogen management for potato production systems

Nitrogen fertilizer requirements are well known for Russet Burbank potatoes grown in Oregon (Gardner et al., 1985) and adjoining areas of Idaho (Painter et al., 1975a). These guidelines were developed to assure maximum production without consideration of N leaching losses to groundwater. Nitrogen uptake by the potato crop can be considerably less than the fertilizer guide application rates based on 1990 samples taken at the Malheur Experiment Station (Shock and Stieber, 1991) and samples taken in southern Idaho (Kleinkopf et al., 1981). New nitrogen fertilizer strategies (Feibert et al., 1998) and irrigation strategies (Shock et al., 1998a) have been demonstrated that simultaneously satisfy crop N requirements and minimize N losses to groundwater and surface water.

Nitrogen and irrigation have important interactive effects on N and water use efficiency, potato yield and quality, and N and water losses to the environment. Meyer and Marcum (1998) obtained maximum tuber yields with 1.1 to 1.2 ETc and 0 to 56 kg ha-1 N in 1992, and with 1.1 to 1.3 ETc and 168 to 224 kg ha-1 N in 1993. Feibert et al. (1998) reexamined nitrogen fertilizer rates and timing for four potato cultivars in the Treasure Valley of Oregon throughout 3 consecutive years on silt loam. They concluded that with careful irrigation scheduling (initiated when the SWT at 0.2-m depth reached 60 kPa and with amounts corresponding to accumulated ETc) less nitrogen fertilizer was required to optimize yield than usual recommendations. Nitrogen at 135 kg ha-1 increased total yield in 19-23% compared to the 0 N rate check treatment.

Optimal potato petiole N levels through the growing season are known for Russet Burbank (Jones and Painter, 1974). Potato petiole analyses should be incorporated into commercial N and irrigation management strategies.

## 6. Irrigation induced leaching and erosion

Effects of excess potato irrigation on promoting nitrate leaching loss to ground water have been discussed (Hill, 1984; Wright and Stark, 1990; Ojala et al., 1990). Nitrate losses under sprinkler-irrigated potatoes were demonstrated (Saffigna et al., 1977). Recently we have shown that it is possible to carefully match sprinkler water application to potato ETc and stage of development to minimize nitrate leaching while assuring good tuber quality (Feibert et al., 1998; Shock et al., 1998a). Waddell et al. (2000) were able to minimize nitrogen-leaching losses under potato through drip irrigation.

The role of sprinkler irrigation efficiency for the reduction of nitrate leaching to groundwater had not been evaluated in eastern Oregon or southwestern Idaho. Recent research in Malheur County, Oregon, placed emphasis on nitrogen fertilization efficiency for onion (Allium cepa) (Shock et al., 1991) and improved recovery of residual soil nitrogen by deep-rooted crops (Miller et al., 1991; Stieber and Shock, 1991; Shock et al., 1998b, 2000). Feibert et al. (1998) demonstrated that N fertilizer applications for potato could be reduced with careful sprinkler irrigation. Nitrate

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leaching could not be economically reduced for potato by reductions in irrigation below crop evapotranspiration because yields and economic return were lost (Shock, et al., 1998a, 2002b, 2003a).

Techniques to reduce irrigation-induced erosion for Treasure Valley potato production on sloping ground have been described using furrow mulching wheat straw and treatment of irrigation water or furrows with polyacrylamide (Shock et al. 1997; Shock and Shock, 1997).

## 7. Potato yield and quality response to water

Potato yield and grade is diminished by relatively mild water stress (Epstein and Grant, 1973). They reported that potato plants begin to experience water stress when soil water tension exceeds 25 kPa. Potato tuber grade, as determined by shape, smoothness, and freedom from visible defects such as growth cracks, dumbbells, and knobs, is highly sensitive to irrigation management deficiencies (Robins and Domingo, 1956; van Loon, 1981). In general, fluctuations in water availability result in more tubers in lower grades, and fewer tubers grading USDA #1. Under furrow and sprinkler systems, reductions in water applications for potato below full replacement of crop evapotranspiration, when silt loam soil is allowed to become drier than 60 kPa, result in yield reduction and loss of economic return (Shock et al., 1998a). With drip irrigation on silt loam Umatilla Russet yields reduced whenever the SWT exceeded the threshold of 30 kPa (Shock et al., 2002a).

The proportion of misshapen tubers is directed related to SWT irrigation criteria. Eldredge et al. (1992) found that a single transient SWT stress drier than 50 kPa increased misshapen Russet Burbank tubers. Pereira and Villa Nova (2002), investigating the effect of three SWT irrigation criteria on tuber yield and grade at Botucatu, SP, Brazil observed that potatoes irrigated at a 15 kPa-SWT to fully replace ETc had higher yields and better quality than those when irrigated at 33 and 53 kPa. Water stress and/or wide variations in soil moisture content have been associated with: (i) secondary growth, (ii) growth cracks, (iii) other tuber malformations, including physiological disorders such as brown center, hollow heart, and translucent end; (iv) bruise susceptibility, and (v) heat stress (Eldredge et al., 1992, 1996; Hooker, 1981; Hiller et al., 1985; MacKerron and Jefferies, 1985; Painter and Augustin, 1976; Rex and Mazza, 1989; Shock et al., 1993b).

Quality of tubers grown for processing into frozen French fries is sensitive to water stress (Eldredge et al., 1992, 1996; Shock et al., 1993b). Water stress during early tuber bulking reduces specific gravity, and increases reducing sugars associated with dark stem-end fry color. When these defects, as measured at harvest, exceed contract specifications, grower returns are reduced by contract penalty clauses. Dark-ends may become more severe after tubers have been stored (Eldredge et al., 1996). The timing of water stress is important, water stress before tuber initiation has no deleterious effect on tuber quality (Shock et al., 1992), while stress later during tuber bulking can cause dark stem-end fry color and reduced specific gravity (Eldredge et al., 1992, 1996; Shock et al., 1993b).

### *7. 1. Whole plant responses*

Jones and Johnson (1958) described the reduction in potato yield caused by water stress. Through the use of a line source sprinkler system, Hang and Miller (1986) showed how a moisture gradient affects plant top growth, tuber yield and tuber grade. Water application had to remain near potential evapotranspiration for maximum tuber yield and grade. Line source sprinklers have also been used to evaluate the effects of simultaneously varying moisture and nitrogen levels on

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potato plant development and assimilate partitioning (Susnoschi and Shimshi (1985); Shimshi and Susnoschi (1985)). MacKerron and Jefferies (1986) have shown that increased duration of water stress before tuber initiation reduces tuber set per stem. Shock et al. (1992) demonstrated that reduced tuber set in the Treasure Valley was related to the duration of water stress drier than 60 kPa.

### *7. 2. Grade of tubers*

Reviews by Kunkel (1957) and Kunkel and Gardner (1958) related the yield and grade of Russet Burbank potatoes to moisture stress. Corey and Myers (1955) determined that the proportion of misshapen tubers was directly related to drier soil water tension. Eldredge et al. (1992) found that a single transient soil water tension stress drier than 50 kPa increased misshapen tubers.

### *7. 3. Translucent end tubers*

Penman (1929) was one of the first authors to discuss the importance of translucent-end potatoes. Numerous authors have suggested that translucent-end potatoes are caused by early season moisture stress (Murphy (1936), Nielson and Sparks (1953), Kunkel (1957), Kunkel and Gardner (1958), and Lugt (1960)). Iritani and Weller (1973a, 1973b) and Iritani et al. (1973) produced translucent-end potatoes by subjecting plants grown in Washington to two weeks of moisture stress in late June. Translucent-end tubers that develop jelly-end rot are graded as culls.

### *7. 4. Sugar ends*

Sugar-ends (tuber) result in dark-ends (French fries), and are related to translucent-ends (tuber) and jelly-ends (tuber). Owings et al. (1978) reproduced the results of Iritani and Weller (1973a) causing sugar-end potatoes with late June stress. Shock et al. (1992) subjected potatoes to water stress in May and the beginning of June and found that early season stress was negatively correlated with sugar-end fry colors. Sugars were increased in the stem (basal) end of the tubers compared to the tuber bud (apical) end following transient stress during tuber bulking at MES (Shock et al., 1993a; Eldredge et al., 1996). Research conducted at MES determined that increases in reducing sugars occurred more than two weeks after transient water stress (Shock et al., 1993b; Eldredge et al., 1996), which suggests that water stress causes enzymatic or membrane changes that eventually result in the loss of cellular control of sugar metabolism and the onset of sugar-ends and translucent ends. If these results are correct, the published understanding of sugar-ends will need revision. Sowokinos et al. (2000) demonstrated the importance of specific tuber starch and sugar enzymes in the development of sugar-ends.

Jackson et al. (1973) exposed potatoes to season long moisture gradients at Hermiston and Madras during 1972, a year with little sugar-end incidence in commercial fields. Daily irrigations tended to reduce the incidence of sugar-ends in tubers at Hermiston. A season long irrigation criterion of 50-kPa soil water deficit tended to favor lighter fry colors than irrigation criteria of 100 or 200 kPa. Painter (1975b) observed no fry color differences between potatoes irrigated at 25% available moisture season long and those irrigated at 65% available moisture, which proved to be consistent with later findings where potatoes were stressed all season (Shock et al., 2002b, 2003a). Eldredge et al. (1996) tested Russet Burbank potatoes under a range of 20 kPa

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increments of transient soil water tension after tuber initiation and found increased sugar-ends after a single episode of water stress drier than 80 kPa.

Kincaid et al. (1993) reviewed the role of temperature on tuber development and demonstrated that sugar ends are increased by increases in soil temperature. The relative roles of water stress and temperature stress on potato defects are poorly defined. Water stress is often associated with increased canopy and soil heating in the field. In most field trials where water stress has been imposed and measured, canopy and soil temperatures have not been measured.

## 8. Potato variety factor

Over the past six years the tri-state variety development group has made major strides in developing new varieties and experimental lines with effective resistance to a number of diseases and physiological defects (Hane et al. 2003; Mosley et al. 2001a, 2000a, 2000b, 2000c; Novy et al. 2003; Rykbost at al. 2003). The working group has become effective at screening for the right set of effective attributes. Varieties are now available such as Umatilla Russet, Russet Legend, and Wallowa Russet with tolerance to sugar ends. Released varieties include Ranger, Willamette, Wallowa, Umatilla, Modoc, Winema, Mazama, Legend, Century, Bannock, Alturas, Klamath, Gem, and GemStar (Hane et al., 2003; Mosley et al., 2000a, 2000b, 2000c, 2001a, 2001b, 2002; Novy et al., 2002, 2003).

Adoption of the new varieties by food processors in the Treasure Valley has lagged, although potato processors in other countries and in other US production regions have eagerly adopted some of these new varieties.

Potato may also respond differently to either deficit irrigation or total seasonal crop evapotranspiration under non-limiting soil water supply. Shock et al. (2003a) studied the effect of different water application rates on the performance of two newly released potato cultivars (Umatilla Russet and 'Russet Legend') and four established cultivars in the Treasure Valley of Oregon (Russet Burbank, Shepody, 'Frontier Russet', and Ranger Russet) on silt loam. They observed that Umatilla Russet showed a higher yield potential at ideal water application rates, and Russet Legend was the only cultivar tolerant to deficit irrigation treatments.

Kleinkopf (1979) found that Russet Burbank was more sensitive than the Butte variety in forming misshapen tubers under water stress. Kleinkopf (1979), Iritani and Weller (1977), and Shock et al. (1993a) among others have demonstrated that reducing sugar concentrations vary among varieties.

## 9. Interaction of irrigation with potato diseases and pests

Irrigation management affects disease severity and management. The increased humidity from irrigation will have greater effects where the macroclimate is humid or sub-humid and be of less importance where it is drier. For potato grown in hot areas, sprinkler irrigation can cool the environment, with possible reductions in physiological defects. However, different irrigation methods can contribute to the occurrence of diseases and pests on the crop depending on site-specific weather pattern.

Wet soil is conducive to most tuber-rotting pathogens. Excessive soil moisture following planting can promote seed piece decay and an erratic emergence. Excessive irrigation can also erode hills, thus exposing shallow-set tubers to greening or sunscald and infection by early and late blight pathogens (Rowe and Secor, 1993).

Intensively managed irrigated cropping systems may develop potato early die. Avoiding over-

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irrigation, or even keeping soils a little dry early in the season before tuber initiation may reduce the amount of root infection by V. dahliae, a major component in early die. On the other hand, avoiding excessive plant water stress during the tuber bulking growth stage, which usually coincides with the warmest part of the season, may help decrease the severity of early die (Cappaert et al., 1994).

Potato vines that remain wet for long periods create a microenvironment conducive to early blight (Alternaria solani), late blight (Phytophthora infestans), white mold (Sclerotinia sclerotiorum), and blackleg (Rhizoctonia solani) (Curwen, 1993). The timing of these diseases and associated crop losses vary regionally with yearly weather patterns, and can be affected by irrigation methods, which increase or decrease the duration of high humidity in the crop canopy.

Consistently rainy summer or fall weather promotes late blight. However, in recent years epidemics of late blight have developed in potato crops in arid production areas of the Pacific Northwest (Stevenson, 1993). Irrigation that tends to keep the foliage wet may contribute to this developing risk. Potatoes cultivated under center pivot irrigation can receive a relatively low volume of irrigation water for a long time near the pivot, favoring late blight occurrence. Johnson et al. (2003) showed that the incidence of late blight tuber rot significantly increased as the amount of irrigation water applied increased, and was significantly greater within 30 m of the pivot than at greater distances. Long duration sprinkler irrigation also favored late blight in Oregon and California (Shock et al. 2003b). Cohen et al. (2000) showed that under overhead sprinkler irrigation the proportion of potato leaflets containing late blight oospores and the number of oospores per leaflet were dependent on the soil water regime.

At present the more humid area at the center of center pivot irrigation systems serves as a focus for the development and spread of potato late blight. We hypothesize that with drip irrigation it is possible to reduce relative humidity of the air in potato production systems as such to reduce potato late blight pressure. Irrigation scheduling and pesticide timing for more effective nematode control and control of early-die syndrome have the potential to increase potato yield and quality, offsetting drip system costs. However, these factors need to be better understood.

While avoiding developing high humidity in the canopy, adequate soil moisture is essential not only for potato yield and quality but also for pest management strategies. Adequate soil moisture helps reduce the attack of cutworms (Spodoptera litura) and mites (Tetranychus spp and Tenuipalpidaee spp). Potato tubermoth (Phthorimaea operculella) and its larvae are repelled by soil moisture. Soil moisture also reduces formation of cracks in the soil, which allow the entry of potato tubermoth and its larvae (Grewal and Jaiswal, 1990). Irrigation scheduling based on ETc and SWT can account for the local climate and keep the soil from becoming too dry. Soils for potato production must be adequately well drained to minimize the occurrence of crop sanity problems.

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## References

Campbell, G.S., and G.W. Gee. 1986. Water potential: miscellaneous methods. In A. Klute (ed.) Methods of Soil Analysis. Part 1. 2nd ed. Agronomy 9:619-633.

© Sakia.org e-publish 2006, all rights reserved.
http://www.sakia.org/

Campbell, G.S., and D.J. Mulla, 1990. Measurement of soil water content and potential. In Stewart, B.A., and D.R. Nielson (ed.) Irrigation of Agricultural Crops. Agronomy 30:127-142.

Cappaert, M.R., M.L. Powelson, N.W. Christensen, W.R. Stevenson, and D.I. Rouse. 1994. Assessment of irrigation as a method of managing potato early dying. Phytopathology 84:792-800.

Cassel, D.K., and A. Klute. 1986. Water potential: tensiometry. In Klute, A. (ed.) Methods of Soil Analysis. Part 1. 2nd ed. Agronomy 9:563-596.

Cohen, Y., S. Farkash, A. Baider, and D.S. Shaw. 2000. Sprinkling irrigation enhances production of oospores of Phytophthora infestans in field-grown crops of potato. Phytopathology 90:1105-1111.

Corey, G.L., and V.I. Myers. 1955. Irrigation of Russet Burbank potatoes in Idaho. Idaho Agric. Exp. Stn. Bull. 246.

Corey, A.T. and G.R. Blake. 1953. Moisture available to various crops in some New Jersey soils. Soil Sci. Soc. Am. Proc. 17:314-317.

DeTar W.R., G.T. Browne, C.J. Phene, and B.L. Sanden. 1996. Real-time irrigation scheduling of potatoes with sprinkler and subsurface drip systems. In Proc Int'l Conf. on Evapotranspiration and Irrigation Scheduling, eds. C.R. Camp, E. J. Sadler, and R.E. Yoder, 812-824. ASAE, St. Joseph, Michigan.

Doorenbos, J., and A.H. Kassam. 1979. Yield response to water. FAO Irrigation and Drainage Paper, No. 33. FAO, Rome, 193p.

Durrant, M.J., B.J.G. Love, A.B. Messeen, and A.P. Draycot. 1973. Growth of crop roots in relation to soil moisture extraction. Ann. Appl. Biol. 74:387-394.

Eldredge, E.P., C.C. Shock, and T.D. Stieber. 1992. Plot sprinklers for irrigation research. Agron. J. 84:1081-1984.

Eldredge, E.P., C.C. Shock, and T.D. Stieber. 1993. Calibration of granular matrix sensors for irrigation management. Agron. J. 85:1228-1232.

Eldredge, E.P., Z.A. Holmes, A.R. Mosley, C.C. Shock, and T.D. Stieber. 1996. Effects of transitory water stress on potato tuber stem-end reducing sugar and fry color. Am. Potato J. 73:517-530.

Eldredge, E.P., C.C. Shock, and L.D. Saunders. 2003. Early and late harvest potato cultivar response to drip irrigation. In Yada, R.Y. (eds) Potatoes - Healthy Food for Humanity. Acta Horticulturae 619:233-239.

Epstein, E., and W.J. Grant. 1973. Water stress relations of the potato plant under field conditions. Agron. J. 65:400-404.

© Sakia.org e-publish 2006, all rights reserved.
http://www.sakia.org/

Fabeiro, C., F. Martin de Santa Olalla, and J.A. de Juan. 2001. Yield and size of deficit irrigated potatoes. Agricultural Water Management 48:255-266.

Feibert, E.B.G., C.C. Shock and L.D. Saunders. 1998. Nitrogen fertilizer requirements of potatoes using carefully scheduled sprinkler irrigation. HortScience 32:262-265.

Fulton, J.M. 1970. Relationship of root extension to the soil moisture level required for maximum yield of potatoes, tomatoes and corn. Can. J. Soil Sci. 50:92-94.

Gardner, E.H., T.L. Jackson, and L. Fitch. 1985. Fertilizer guide for irrigated potatoes (Columbia Basin-Malheur County) Oregon State University Extension Service FG57.

Gardner, W.H. 1986. Water content. In A. Klute (ed.) Methods of Soil Analysis. Part 1. 2nd ed. Agronomy 9:493-544.

Grewal, J.S., and V.P. Jaiswal. 1990. Agronomic studies on potato under all India coordinated potato improvement project. CPRI, Technical Bulletin No. 20. 106 p.

Hane, D.C., A.R. Mosley, S.R. James, K.A. Rykbost, C.C. Shock, S.L. Love, D.L. Corsini, J.J. Pavek, R.E. Thornton, B.A. Charlton, E.P. Eldredge, and S. Yilma. 2003. Wallowa Russet: a full season long russet for processing and fresh market. Am. J. Potato Res. 80:289-294.

Hang, A.N., and D.E. Miller. 1986. Yield and physiological responses of potatoes to deficit, high frequency sprinkler irrigation. Agron. J. 78:436- 440.

Hegney, M.A., and H.P. Hoffman. 1997. Potato irrigation – development of irrigation scheduling guidelines. Final Report, Horticultural Research and Development Corporation Project NP 6. Agriculture Western Australia. 114p.

Hill, W.A. 1984. Effect of nitrogen nutrition on quality of three important root/tuber crops. IN R.D. Hauck (ed.) Nitrogen in crop production, ASA CSSA SSA.

Hill, W.A., R.J. Hanks, and J.L. Wright. 1985. Crop yield models adapted to irrigation scheduling programs. Utah Agric. Exp. Sta. Res. Rep. 99.

Hiller, L.K., D.C. Koller, and R.E. Thornton. 1985. Physiological Disorders of Potato Tubers. p. 389-455. In: Potato Physiology. P.H. Li, (ed.).

Hiller, L.K., and D.C. Koller. 1984. Effect of early season moisture levels and growth regulator applications on internal quality of Russet Burbank potato tubers. Proc. Wash. State Potato Conf. 23:67-73.

Holder, C.B., and J.W. Cary. 1984. Soil oxygen and moisture in relation to Russet Burbank potato yield and quality. Am. Potato J. 61:67- 75.

Hooker, W.J. 1981. Secondary growth and jelly end rot. In: Compendium of Potato Diseases (W.J. Hooker, Ed.). Am. Phytopathological Soc., St. Paul, MN, p. 12-13.

Hutchinson, C.M., W.A. Tilton, P.K. Livingston-Way, and G.J. Hochmuth. 2002. Best management

© Sakia.org e-publish 2006, all rights reserved.
http://www.sakia.org/

practices for potato production in Northeast Florida. Extension Brochure HS877. 3p. Available on-line at http://edis.ifas.ufl.edu/CV279

Iritani, W. M., and L. D. Weller. 1977. Changes in reducing sugar content of Kennebec and Russet Burbank tubers during growth and post-harvest holding temperatures. Am. Potato J. 54:395-404.

Iritani, W. M., and L.D. Weller. 1973a. The development of translucent end potatoes. Am. Potato J. 50:223-233.

Iritani, W.M., and L. D. Weller. 1973b. Differences in dry matter content of apical and basal portions of Russet Burbank potatoes. Am. Potato J. 50:389-397.

Iritani, W.M., L. Weller, and T.S. Russel. 1973. Relative differences in sugar content of basal and apical portions of Russet Burbank potatoes. Am. Potato J. 50:24-21.

Jackson, T.L., C. Ullery, T. Davidson, M. Johnson, and G. Carter. 1973. Effects of irrigation and nitrogen fertilization on processing quality and distribution of sugars in Russet Burbank potatoes, Hermiston, Madras and Klamath Falls, 1972 unpublished data. Dept. of Soil Sci., OSU.

Jensen, L., and B. Simko. 1991. Malheur County crop survey of nitrogen and water use practices. Oregon State University Agricultural Experiment Station, Special Report 882:187-198.

Johnson, D.A., M. Martin, and T.F. Cummings. 2003. Effect of chemical defoliation, irrigation water, and distance from the pivot on late blight tuber rot in center-pivot irrigated potatoes in the Columbia basin. Plant Dis. 87:977-982.

Jones, J.P. and C.G. Painter. 1974. Tissue analysis, a guide to nitrogen fertilizer of Idaho Russet Burbank potatoes. University of Idaho CIS No. 240.

Jones, S.T., and W.A. Johnson. 1958. Effect of irrigation at different minimum levels of soil moisture and of imposed droughts on yield of onions and potatoes. Proc. Am. Soc. Hort. Sci. 71:440-445.

Kincaid, D.C., D.T. Westerman, and T.J. Trout. 1993. Irrigation and soil temperature effects on Russet Burbank quality. Am. Potato J. 70:711-723.

Kleinkopf, G.E., D.T. Westermann, and R.B. Dwelle. 1981. Dry matter production and nitrogen utilization by six potato cultivars. Agron. J. 73:799-802.

Kleinkopf, G.E. 1979. Translucent-end of potatoes. Univ. of Idaho, Current Information Series No. 488. August 1979.

Kunkel, R., and W.H. Gardner. 1958. Blackspot of Russet Burbank potatoes. Amer. Soc. Hort. Sci. 73:436-444.

Kunkel, R. 1957. Factors affecting the yield and grade of Russet Burbank potatoes. Colorado State Univ. Tech. Bull. No. 62, June 1-42.

© Sakia.org e-publish 2006, all rights reserved.
http://www.sakia.org/

Larson, G.F. 1985. Electrical sensor for measuring moisture in landscape and agricultural soils. U.S. Patent 4,531,087. Date issued: 23 July.

Letey, J. 1985. Irrigation uniformity as related to optimum crop production - additional research is needed. Irrig. Sci. 6:253-263.

Lugt, C. 1960. Second growth phenomena. Eur. Potato J. 3:307-325.

MacKerron, D.K.L., and R.A. Jefferies. 1986. The influence of early soil moisture stress on tuber numbers in potato. Potato Res. 29:299-312.

MacKerron, K.D., and R.A. Jefferies. 1985. Observations on the effects of relief of later water stress in potato. Potato Res. 28:349-359.

Meyer, R.D., and D.B. Marcum. 1998. Potato yield, petiole nitrogen, and soil nitrogen response to water and nitrogen. Agron. J. 90:420-429.

Miller, J.G., T.D. Stieber, C.C. Shock, and L.D. Saunders. 1991. Soil nitrogen recovery by Stephens wheat and Hesk barley. Agronomy Abstracts p. 295.

Mosley, A.R., D.C. Hane, S.R. James, K.A. Rykbost, C.C. Shock, S. Yilma, B.A. Charlton, E.P. Eldredge and F. Rhodes. 2002. Oregon National Potato Germplasm Evaluation and Enhancement Report, 2000. K. Haynes, ed. USDA, ARS, Beltsville Agricultural Research Center, Beltsville, Maryland, in press.

Mosley, A.R., D.C. Hane, S.R. James, K.A. Rykbost, C.C. Shock, S. Yilma, B.A. Charlton, E.P. Eldredge and F. Rhodes. 2001a. Oregon National Potato Germplasm Evaluation and Enhancement Report, 1999. K. Haynes, ed. USDA, ARS, Beltsville Agricultural Research Center, Beltsville, Maryland, pp. 267-278 in ARS-158.

Mosley, A.R., K.A. Rykbost, S.R. James, C.C. Shock, B.A. Charlton, J.J. Pavek, S.L. Love, D.L. Corsini, and R.E. Thornton. 2001b. Klamath Russet: A full-season, fresh market, long russet. Am. J. Potato Res. 78:377-381.

Mosley, A.R., S.R. James, D.C. Hane, K.A. Rykbost, C.C. Shock, B.A. Charlton, J.J. Pavek, S.L. Love, D.L. Corsini, and R.E. Thornton. 2000a. Umatilla Russet: A full season long russet for processing and fresh market use. Am. J. Potato Res. 77:83-87.

Mosley, A.R., S.R. James, K.A. Rykbost, D.C., Hane, C.E. Stanger, C.C. Shock, J.J. Pavek, D.L. Corsini, J.C. Miller, Jr., S.L. Love, R.E. Thornton, D.G. Holm and R.E. Voss. 2000b. Century Russet: A high yielding fresh market cultivar with Verticillium resistance. Am. J. Potato Res. 77:161-165.

Mosley, A.R., S.R. James, C.C. Shock, D.C. Hane, K.A. Rykbost, B.A. Charlton, D.G. Holm, S.L. Love, D.L. Corsini, J.J. Pavek, and R.E. Thornton. 2000c. Russet Legend: A full season long russet for processing and fresh market use. Am. J. Potato Res. 77:77-81.

Murphy, P.A. 1936. Some effects of drought on potato tubers. Empire J. Exp. Agr. 4:230-246.

© Sakia.org e-publish 2006, all rights reserved.
http://www.sakia.org/

Neibling, H. and R. Brooks. 1995. Potato production using subsurface drip irrigation - Water and nitrogen management. In Proc 5th Int'l. Microirrigation Congress, ed. F.R. Lamm, 656-663. ASAE, St. Joseph, Michigan.

Nielson, L.W. and W.C. Sparks. 1953. Bottleneck tubers and jelly-end rot in the Russet Burbank potato. Univ. of Idaho Res. Bul. 23 October 1-24.

Novy, R.G., D.L. Corsini, S.L. Love, J.J. Pavek, A.R. Mosley, S.R. James, D.C. Hane, C.C. Shock, K.A. Rykbost, C.R. Brown, and R.E. Thornton. 2003. Alturas: a multi-purpose russet potato cultivar with high yield and tuber specific gravity. Am. J. Potato Res. 80:295-301.

Novy, R.G., D.L. Corsini, S.L. Love, J.J. Pavek, R.L. Mosley, S.R. James, D.C. Hane, C.C. Shock, K.A. Rykbost, C.R. Brown, and R.E. Thornton. 2002. Bannock Russet: A dual-purpose, russet potato variety notable for its high U.S. No. 1 yield and multiple disease resistances. Am. J. Potato Res. 79:147-153.

Ojala, J.C., J.C. Stark, and G.E. Kleinkopf. 1990. Influence of irrigation and nitrogen management on potato yield and quality. Am. Potato J. 67:29-43.

Owings, T.R., W.M. Iritani, and C. W. Nagel. 1978. Respiration rates and sugar accumulation in normal and moisture stressed Russet Burbank potatoes. Am. Potato J. 55:211-220.

Painter, C.G., and J. Augustin. 1976. The effect of soil moisture and nitrogen on yield and quality of the Russet Burbank. Potato. Am. Potato J. 53:275-284.

Painter, C.G., D.O. Everson, A.J. Waltz, R.R. Romanko, A. Czernik, J.R. Jaeger, W.A. Henninger, and C.D. Gross. 1975a. Idaho fertilizer guide - potatoes. University of Idaho CIS No. 261.

Painter, C.G., D.0. Everson, A. J. Waltz, R. R. Romanko, A. Czernik, J. R. Jaeger, W. A. Henninger, and C. D. Gross. 1975b. Translucent-end potatoes in Southwestern Idaho. Univ. of Idaho Misc. Series No. 24.

Penman, F. 1929. Glassy end of potatoes. J. Dept. of Agric. Victoria 27:449-458.

Pereira, A.B., and N.A. Villa Nova. 2002. Physiological parameters and potato yield submitted to three irrigation levels. Eng. Agric. (Jaboticabal, Brazil) 22:127-134.

Pereira, A.B., J.F. Pedras, N.A. Villa Nova, and D.M. Cury. 1995. Water consumption and crop coefficient of potato (*Solanum tuberosum* L.) during the winter season in municipality of Botucatu-SP. Rev. Bras. Agrometeorol. 3:59-62.

Powelson, M.L., and N.W. Christensen. 1991. Water and verticillium interactions in potato early dying (Abstract). Am. Potato J. 66:541.

Rex, B.L., and G. Mazza. 1989. Cause, control, and detection of hollow heart in potatoes: a review. Am. Potato J. 66:165:183.

Robins, J.S., and C.E. Domingo. 1956. Potato yield and tuber shape as affected by severe soil

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http://www.sakia.org/

moisture deficits and plant spacing. Agron. J. 48:488-492.

Rowe, R.C., and G.A. Secor. 1993. Managing potato health from emergence to harvest. p.35-40. In R.C. Rowe (ed.) Potato Health Management. The American Phytopathological Society, ASP Press, Wooster, Ohio.

Rykbost, K.A., S.R. James, A.R. Mosley, B.A. Charlton, D.C. Hane, C.C. Shock, R. Voss, R.H. Johansen, S.L. Love, and R.E. Thornton. 2003. Modoc: A potato variety with bright red skin and early maturity for fresh market. Am. J. Potato Res. 80:235-240.

Saffigna, P.G., D.R. Keeney, and C.B. Tanner. 1977. Nitrogen, chloride, and water balance with irrigated Russet Burbank potatoes in a sandy soil. Agron. J. 69:251-257.

Saffigna, P.G., C.B. Tanner, and D.R. Keeney. 1976. Non-uniform infiltration under potato canopies caused by interception, stemflow, and hilling. Agron. J. 68:337-342.

Sammis, T.W. 1980. Comparison of sprinkler, trickle, subsurface and furrow irrigation methods for row crops. Agron. J. 72(5):701-704.

Shae, J.B., D.D. Steele, B.L. Gregory. 1999. Irrigation scheduling methods for potatoes in the Northern Great Plains. American Society of Agricultural Engineers 42:351-360.

Shimshi. D., and M. Susnoschi. 1985. Growth and yield studies of potato development in a semi-arid region. 3. Effect of water stress and amounts of nitrogen top dressing on physiological indices and on tuber yield and quality of several cultivars. Potato Res. 28:177-191.

Shock, C.C., and C.A. Shock. 2004. Comparison of the AM400 and Watermark Monitor for precise irrigation scheduling. In Oregon State University Agricultural Experiment Station, Special Report 1055:257-260.

Shock, C.C. 2003. Soil water potential measurement by granular matrix sensors. In Stewart, B.A. and Howell, T.A. (eds) The Encyclopedia of Water Science. Marcel Dekker. p 899-903.

Shock, C.C., E.B.G. Feibert, L.D. Saunders, and S.R. James. 2003a. Umatilla Russet and Russet Legend potato yield and quality response to irrigation. HortScience 38:1117-1121.

Shock, C.C., C.A. Shock, L.D. Saunders, K. Kimberling, and L. Jensen. 2003b. Predicting the spread and severity of potato late blight (Phytophthora infestans) in Oregon, 2002. In Oregon State University Agricultural Experiment Station, Special Report 1048:130-138.

Shock, C.C., E.P. Eldredge, and D. Saunders. 2002a. Drip irrigation management factors for Umatilla Russet potato production. In Malheur Experiment Station Annual Report 2001, 157-169. Special Report 1038, Oregon State University.

Shock, C.C. and E.B.G. Feibert. 2002b. Deficit irrigation of potato. In P. Mountonnet (ed) Deficit Irrigation Practices. Food and Agriculture Organization of the United Nations, Rome. Water Reports 22:47-55. Available on-line at: http://www.fao.org/docrep/004/Y3655E/Y3655E00.htm

Shock, C.C., E.B.G. Feibert, L.D. Saunders, and E.P. Eldredge. 2002c. Automation of Subsurface

© Sakia.org e-publish 2006, all rights reserved.
http://www.sakia.org/

Drip Irrigation For Crop Research. American Society of Agricultural Engineers. World Congress on Computers in Agriculture and Natural Resources. Iguaçu Falls, Brazil. pp. 809-816.

Shock, C.C., M. Seddigh, L.D. Saunders, T.D. Stieber, and J.G. Miller. 2000. Sugarbeet nitrogen uptake and performance following heavily fertilized onion. Agron. J. 92:10-15.

Shock, C.C. 1998. Instrumentos para determinação da umidade do solo. Simpósio de Energia, Automação e Instrumentação. XXVII Congresso Brasileiro de Engenharia Agricola, Poços de Caldas, MG, Brasil.

Shock, C.C., E.B.G. Feibert, and L.D. Saunders. 1998a. Potato yield and quality response to deficit irrigation. HortScience 33:655-659.

Shock, C.C., E.B.G. Feibert, and D. Westermann. 1998b. "On farm" implementation of lower nitrogen fertilizer inputs through nitrogen accounting and validation of organic matter mineralization. Oregon State University Agricultural Experiment Station, Special Report 988:126-134.

Shock, C.C., J.M. Barnum, and M. Seddigh. 1998c. Calibration of Watermark Soil Moisture Sensors for Irrigation Management. Irrigation Association, November, San Diego, CA.

Shock, C.C., and B.M. Shock. 1997. Comparative effectiveness of polyacrylamide and straw mulch to control erosion and enhance water infiltration. In Wallace, A. Handbook Of Soil Conditioners. Marcel Dekker, Inc. New York, NY. pp. 429-444.

Shock, C.C., J.H. Hobson, M. Seddigh, B.M. Shock, T. D. Stieber, and L. D. Saunders. 1997. Mechanical straw mulching of irrigation furrows: soil erosion and nutrient losses. Agron. J. 89:887-893.

Shock, C.C., E.B.G. Feibert, and L.D. Saunders. 1996. Precision irrigation scheduling with granular matrix sensors. Proceedings of the International Conference on Evapotranspiration and Irrigation Scheduling pp. 1105-1108. San Antonio, TX.

Shock, C.C., T.D. Stieber, and E.P. Eldredge. 1993a. A comparison of drip, sprinkler, and furrow irrigation of potatoes. In Oregon State University Agricultural Experiment Station, Special Report 924:138-142.

Shock, C.C., Z.A. Holmes, T.D. Stieber, E.P. Eldredge, and P. Zhang. 1993b. The effect of timed water stress on quality, total solids and reducing sugar content of potatoes. Am. Potato J. 70:227-241.

Shock, C.C., J.D. Zalewski, T.D. Stieber, and D.S. Burnett. 1992. Early season water deficits on Russet Burbank plant development, yield, and quality. Am. Potato J. 69:793-804.

Shock, C.C., and T.D. Stieber. 1991. Nitrogen uptake and removal by selected crops. Oregon State University Agricultural Experiment Station, Special Report 882:182-186.

Shock C.C., T.D. Stieber, J.G. Miller, and L.D. Saunders. 1991. Improved nitrogen fertilizer

© Sakia.org e-publish 2006, all rights reserved.
http://www.sakia.org/

efficiency for onion production. Oregon State University Agricultural Experiment Station, Special Report 882:66-74.

Simonne, E., N. Ouakrim, and A. Caylor. 2002. Evaluation of an Irrigation Scheduling Model for Drip-irrigated Potato in Southeastern United States. HortScience 37(1): 104-107.

Smajstrla, A.G., S.J. Locascio, D.P. Weingartner, D.R. Hensel. 2000. Subsurface drip irrigation for water table control and potato production. Appl. Eng. Agric. 16:225-229.

Solomon, K.H. 1984. Yield related interpretations of irrigation uniformity and efficiency measures. Irrig. Sci. 5:161-172.

Sowokinos, J.R., C.C. Shock, T.D. Stieber, and E.P. Eldredge. 2000. Compositional and enzymatic changes associated with the sugar-end defect in Russet Burbank potatoes. Am. J. Potato Res. 77:47-56.

Stevenson, W.R. 1993. Management of early blight and late blight. p 141-147. In R.C. Rowe (ed.) Potato Health Management. The American Phytopathological Society, ASP Press, Wooster, Ohio.

Steyn, J.M., H.F. Du Plessis, P. Fourie, and T. Ross. 2000. Irrigation scheduling of drip irrigated potatoes. Micro-irrigation technology for developing agriculture. 6th International Micro-irrigation Congress. South Africa. October 22-27, 2000.

Stieber, T.D., and C.C. Shock. 1995. Placement of soil moisture sensors in sprinkler irrigated potatoes. Am. Potato J. 72:533-543.

Stieber, T.D., and C.C. Shock. 1991. Sugar beet nitrogen recovery. In Oregon State University Agricultural Experiment Station Special Report 882:166-170.

Susnoschi, M., and D. Shimshi. 1985. Growth and yield studies of potato development in a semi-arid region. 2. Effect of water stress and amounts of nitrogen top dressing on growth of several cultivars. Potato Res. 28:161-176.

Tanner, C.B. 1981. Transpiration efficiency of potato. Agron. J. 73:59-64.

Thomson, S.J., and C.F. Armstrong. 1986. Calibration of the Watermark model 200-soil moisture sensor. Appl Eng Agric 3:186-189.

Timm, H. and W.J. Flockner. 1966. Responses of potato plants to fertilization and soil moisture under induced soil compaction. Agron. J. 58:153-157.

van Loon, C.D. 1981. The effect of water stress on potato growth, development, and yield. Am. Potato J. 58:51-69.

Waddell, J.T., S.C. Gupta, J.F. Moncrief, C.J. Rosen, and D.D. Steele. 2000. Irrigation- and nitrogen-management impacts on nitrate leaching under potato. Environ. Qual. 29:251-261.

Waddell, J.T., S.C. Gupta, J.F. Moncrief, C.J. Rosen, and D.D. Steele. 1999. Irrigation and

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http://www.sakia.org/

nitrogen management effect on potato yield, tuber quality, and nitrogen uptake. Agron. J. 91:991-997.

Wright, J. L., and J. C. Stark. 1990. Potato. IN B.A. Stewart and D.R. Nielson (eds.) Irrigation of Agricultural Crops. ASA CSSA SSSA. pp. 859-888.

Yoder, R. E., M. J. Haftendorf, and T. Hodges. 1991. Soil water and temperatures in alternate hill structures. Am. Potato J. 68:642.

Zartman, R.E., L. Rosado-Carpio, and R.H. Ramsey. 1992. Influence of trickle irrigation emitter placement on yield and grade distribution of potatoes. HortTechnology 2:387-391.

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