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The Effects of Supplemental Irrigation and Soil Management on Potato Tuber Diseases

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Abstract: The aim of this research was to evaluate the effects of irrigation and soil management on potato tuber diseases. Supplemental irrigation, soil amendment and crop rotation can improve potato growth and tuber yield under drought stress conditions, but may also increase potato tuber diseases. The effects of irrigation, soil amendment and crop rotation on the incidence of tuber diseases were quantified from 1994 to 1997 in potato plots. Surface sprinkler irrigation was applied each year, based on tensiometer or moisture block readings deployed in field plots. Black scurf (*Rhizoctonia solani*), black dot (*Colletotricchum coccodes*), silver scurf (*Helminthosporium solani*) and common scab (*Streptomyces scabei*) diseases were quantified on potato tubers randomly sampled at harvest and kept at storage temperature of 7.2°C before visual disease assessment. The incidence of tuber diseases varied among irrigation treatments, crop rotations and soil amendments. The mean incidence of black scurf, silver scurf and black dot ranged from 3-18, 2-33 and 4-7%, in best, un-irrigated and reduced irrigation, respectively. The incidence of back scurf, silver scurf and black dot diseases ranged from 2.4-10, 0.8-21 and 1-31% on potato tubers grown in plots under green manure rotation crop (peas/vetch). Disease incidences on tubers were 1-28, 0-35 and 2-16% for black scurf, silver scurf and black dot, respectively; when potato plants were grown under small-grain rotation. Soil amendments had significant ($p<0.05$) effects on the incidences of silver scurf disease in 1997 and black dot disease in 1996 and 1997. The interactions of soil amendment with irrigation resulted in significant effects on black scurf incidence in 1994. This research implied that water application may lead to increases in some potato tuber diseases, however; crop rotation and soil amendment may reduce the incidences of selective potato tuber diseases, depending on the type, duration or frequency of supplemental irrigation.

Key words: Water management, crop rotation, soil amendment, tuber diseases, Maine

INTRODUCTION

There are numerous above ground (foliar) and below ground (soil-borne) diseases of potato that have been reported as constraints to productivity in diverse agro-ecological zones of the world (Powelson *et al*., 1993). The disease symptoms often affect various above-ground and below ground parts of potato plants. Foliar diseases such as early blight, late blight and potato viruses are often reported to be more problematic, due to their devastating effects on reductions of photosynthetic leaf area and subsequent defoliation, resulting in tremendous yield loss. Potato diseases that affect below-ground plant parts (roots, stolons and tubers) have previously been less investigated due to the complexity of interactive factors affecting potato plants and tubers. However, further studies and documentation of the biological and edaphic factors that contribute to development of tuber-borne diseases have elucidated the role of these diseases.

One of the major factors contributing to renewed interest in quantifying and assessing soil-borne or potato tuber diseases is the increases in consumption and utilization of potato as table stock or wares, in both developed and developing countries (Scott *et al*., 2000). The increase in consumption and utilization of potato has indirectly influenced industry and consumer considerations of tuber quality especially as they relate to quality appearance and palatability of potato tubers. Similarly, potato tubers shipped for processing at industrial outlets have also been subjected to quality assessment (external appearance, external defects) and documentation of characteristics such as tuber diseases.

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There are many tuber-borne diseases of potato which have been previously reported. Among these are tuber black scurf (*Rhizoctonia solani* Kuhn), black dot (*Colletotricchum coccodes* (Wallr.) S.J. Hughes), silver scurf (*Helminthosporium solani* Durieu and Mont. (Syn.) *Spondylocladium atrovirens* Harz.) and common scab (*Streptomyces scabei*) which are the most common tuber diseases and are known to occur in various potato production regions of the world (Adams *et al*., 1987; Adams and Stevenson, 1990). The potential effects of these diseases on tuber quality, survival, as well as their inoculum potential are of considerable importance and have been the primary justification for studying these diseases.

The research findings from previous studies on tuber diseases have focused primarily on pathogen prevalence of various diseases in diverse agro-ecosystems, as well as methods for pathogen controls or disease management (Carling *et al*., 1989; Johnson and Miliczky, 1993; Larkin and Honeycutt, 2006). Potato cultivars, soil amendments and crop rotations have been extensively examined as management options for potato tuber disease control (Olanya *et al*., 2006; Peters *et al*., 2004; Honeycutt *et al*., 1996). In the above studies, the interactive or complementary effects of irrigation were not investigated. Similarly, the role of fungicides and other chemical compounds for management of foliar and seed-borne, or tuber-borne potato diseases have also been examined.

Among the most important edaphic or environmental factors that influence pathogen infection and disease development on potato and other agronomic crops is moisture or relative humidity. Water management has been shown to provide humid conditions or microclimate favorable for pathogen infection and development of certain diseases (Rotem *et al*., 1970; Olanya *et al*., 2007a, b). In contrast to the detrimental indirect effects of irrigation mentioned above, the positive attributes of water management is linked to the provision of adequate soil moisture for potato growth at critical duration of the cropping seasons (Rotem and Palti, 1969; Lapwood *et al*., 1973; Starr *et al*., 2008). In many other previous research investigations and findings, the occurrences and incidences of tuber-borne diseases have often been examined on a single disease scenario or treatment effect, rather than the interactive effect of various treatment factors on multiple potato diseases, or their development and management in storage environments.

In this study, we examine the effects of supplemental irrigation on the incidence of potato tuber diseases and evaluate the effects of selected soil amendments and crop rotations and their interactive effects on potato tuber diseases This research supplements a previous study conducted during the same time periods, documenting the effects of supplemental irrigation and cultivar effects on tuber-borne potato diseases, in which similar methodology were used even though experimental treatments differed (Olanya *et al*., 2010).

MATERIALS AND METHODS

Site description and plot establishment: The experimental plots at the University of Maine, Aroostook Research Farm in Presque Isle, Maine; were used for the study from 1994 to 1997. The soil at the experimental site is a Caribou gravelly loam (fine-loamy, mixed, frigid isotic Haplorthods). Average air temperature and monthly rainfall totals were the same as previously described (Olanya *et al*., 2010).

Irrigation treatments and potato diseases (1994 to 1995 experiments): Irrigation experiments were examined during the two years. The experiment assessed the effects of supplemental irrigation, soil amendments and crop rotation on potato tuber diseases, The experiments were arranged in split-split plot designs consisting of three irrigation treatments (best, reduced and non-irrigated) during the 1994 to 1995 years. The main plots were irrigation treatments with plot dimensions of 27.2×27.2 m. The sub-plots (9.1×13 m) consisted of two soil amendments and two crop rotations (sub-sub plot) within the main plots and a single potato cultivar (superior) was used. In the irrigated treatments, supplemental irrigation and subsequent scheduling of irrigation events were initiated and conducted based on gravimetric soil water content and gypsum blocks readings in 1994 and 1995. There were four replications per experimental treatment.

The irrigation system used for the experiment was overhead sprinklers with plastic pipes. Buffer zones (3 to 5 m wide) were maintained around each plot to isolate irrigation treatments and minimize interplot interference with water applications. In the best irrigation treatment, water was applied to maintain optimum plant and soil moisture availability, based on gypsum blocks and tensiometer readings. In reduced irrigation treatment, water was applied to field plots from tuber initiation to mid-bulking with a goal of maintaining 50% Plant Available Water (PAW). A non-irrigated control or check had no water applied to field plots. In 1994, the initial irrigation application was started on July 18 and final application was on August 20. In 1995, initial and final irrigation applications were on July 3 and August 28, respectively.

Irrigation treatments and potato diseases (1996 to 1997 experiments): From 1996 to 1997, the experiments were conducted to assess the effects of supplemental irrigation, soil amendments and crop rotations on potato tuber diseases. Two irrigation treatments (irrigated and un-irrigated) were used as the main plots. The water applications consisted of: irrigation at 35% soil moisture depletion where water was applied at 1.42 cm per application and the un irrigated control (check) where no water was applied to field plots. The experiments were arranged in split-split plot designs consisting of the two irrigation treatments, two soil amendments and two crop rotations. The main plots were irrigation treatments with plot dimensions of 27.2×27.2 m. The sub-plots (9.1×13 m) consisted of two soil amendments and two crop rotations (sub-sub plots) within the main plots. In 1996 and 1997, tensiometer readings were used to determine soil water content for scheduling irrigation events. The cultivar Superior was planted in all experiments.

Crop rotation and potato diseases (1994 to 1997 experiments): From 1994 to 1997, two crop rotations were used. Crop rotation treatments consisted of: (1) small grains (oats cv. Porter) and, (2) green manure crop (mixture of oats, peas and vetch). The small grains crop was seeded at the rate of 201.78 kg ha^{-1} and the green manure crops (oats, peas, vetch) were seeded at the rates of 53.8, 168.15, 33.63 kg ha^{-1} and broadcast as mixtures; respectively. After maturity, the crops were subsequently plowed in the soil in the fall in each year.

Soil amendment and potato diseases (1994 to 1997 experiments): During the 1994 to 1995 experiments, the two soil amendment treatments consisted of: (1) small grain + manure + compost (Grainmc) and (2) green manure + manure + compost (Greenmc). Straw from small grain crop (oats) and green manure crop (peas vetch) was plowed under field soil while manure and compost were applied to the soil surface at the rates of 44.84 and 22.42 metric t ha^{-1}, respectively; and then disked. The compost contained mixture of waste potato tubers, saw dust, wood ash. The manure amendment consisted of cow dung which was obtained from beef cattle. In the 1996 to 1997 experiments, two soil amendments which differed from that of 1994 to 1995 were used. The soil treatments were: (1) amended by the addition of manure + compost and consisted of the same constituents as described above, or (2) non-amended treatment. The application rates for soil amendments with manure and compost during 1996 and 1997 were 44.84 and 22.42 metric t ha^{-1}.

Foliar disease control: Foliar diseases in field plots were controlled by the application of foliar fungicides namely mancozeb during 1994 and 1995. In 1996 to 1997, foliar disease management was accomplished by the application of chlorothalonil.

Disease assessment: The incidence of various tuber diseases such as: black scurf, silver scurf, black dot and common scab were assessed visually after harvest on a sample size of 200 tubers per treatment (James, 1971). The sampling methods and storage conditions were the same as those previously described (Olanya *et al*., 2010). The occurrence of black dot and silver scurf on potato tubers were differentiated based on observation of colletotrichum under dissecting scope immediately after washing of tuber samples. The presence of silver scurf was verified by microscopic observation of spores of *H. solani* obtained on two-sided tape. The potato tubers with black scurf and containing symptoms characteristic of *R. solani* sclerotia, as well as common scab were also identified. Potato tubers with and without symptoms was counted from a sample lot and the incidence of tuber diseases on potato tubers were then determined (Number of tubers diseased/Total number of tubers assessed×100).

Data analyses: Prior to the analysis, percent disease incidence, data were subjected to tests for normality of variances using the Shapiro-Wilk test of residuals (SAS Institute, Cary, NC, USA). Where assumptions (additivity, constancy of variance, normality) were not met, data transformation was accomplished prior to analysis of variance of the percentage disease incidence data. To determine the significance of treatment effects, the percentages of black scurf, silver scurf, black dot and common scab incidences were analyzed for each disease separately during each cropping year using the GLM procedures of SAS (SAS Institute, Cary, NC, USA). Where significant treatment effects were observed, means were separated using the least significant difference ($p = 0.05$). The average disease incidences (%) were also shown graphically to illustrate the interaction of some tuber diseases and treatment effects.

RESULTS

Irrigation effects on potato tuber diseases: The irrigation effects were significant ($p<0.05$) for tuber diseases consisting of black scurf and silver scurf in 1994 and for black scurf only in 1995 (Fig. 1a, b). The irrigation application significantly ($p<0.05$) affected the incidence of

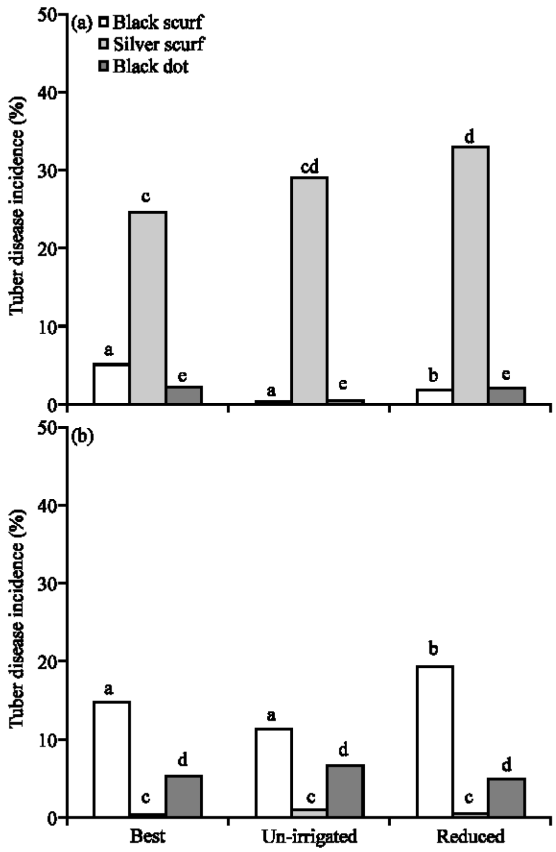

Fig. 1: Effect of supplemental irrigation on the percent incidence of tuber diseases on Superior cultivar. The irrigation treatments refer to best (available optimum plant and soil water), reduced (water applied from tuber initiation to mid-bulking and maintained at 50% PAW) and un-irrigated (check). Data represent average disease levels and different lower case letters for each disease among irrigation treatments indicate significant differences (p<0.05) based on Fisher's LSD statistics. (a) 1994 and (b) 1995

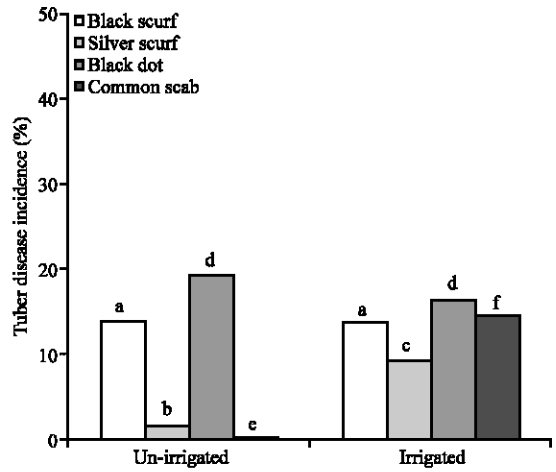

Fig. 2: Effect of irrigation treatment on the percent incidence of tuber diseases during the 1997 cropping year. Field plots were either irrigated, or not irrigated and cropped to potato cultivar Superior. Different lower case letters for each disease between irrigation treatments indicate significant differences (p<0.05) based on Fisher's LSD statistics

silver scurf and common scab diseases during 1997 (Table 1, Fig. 2). The average incidence of tuber diseases was 0.3, 1.7, 13.9 and 19.3% for common scab, silver scurf, black scurf and black dot, respectively; under un-irrigated plots. In the irrigated treatments tuber disease levels were 14.6, 9.3, 13.7 and 16.5% for the same diseases, respectively.

Crop rotation effects on potato tuber diseases: Crop rotation treatments did not significantly affect the incidence of silver scurf during 1994 and 1995 cropping years (Table 1). Crop rotation significantly impacted silver scurf and black dot disease incidences in 1997 (Table 1). The average incidence of black dot was 15.8 and 21% on tubers planted under green manure and small grain rotations, respectively. Mean disease incidence for silver scurf was 3.1 and 6.2% on tubers in which potato was planted in plots rotated with green manure (oats, peas and vetch) and small grain (oats) when data was averaged across irrigation treatments during the same year (Fig. 3). The mean incidence of black dot on tubers was significantly (p<0.05) greater on potato planted in plots where green manure (21.3%) was used as a rotation crop than on potato planted in plots rotated to small grains (12.4%) under irrigation. The difference in black dot incidence on tubers between the two rotations was also observed when the treatment was non-irrigated. The incidence of silver scurf disease on potato tubers obtained from green manure and small grain rotation plots was 5.2 and 12.8%, respectively (Fig. 3).

Soil amendment effects on potato tuber diseases: The addition of soil amendments did not significantly affect the incidence of black dot during the 1994 and 1995 cropping years. Soil amendment had significant (p<0.05) effects on black dot in 1996 and 1997 (Table 1). The incidence of black scurf disease in 1994 was 6% on potato tubers and significantly (p<0.05) higher in plots amended with grain + manure + compost compared to 0.8% on tubers harvested from plots amended with green manure+manure+compost (Fig. 4).

Table 1: Analysis of variance on the effects of supplemental irrigation, soil amendments and crop rotation on potato tuber diseases

		Black scurf		Silver scurf		Black dot		Common scab	
Source of variation	df	1994	1995	1994	1995	1994	1995	1994	1995
Irrigation and soil management (1994-1995)									
Irrigation[W]	2	0.7756	0.0208**	0.0547*	0.5513	0.1733	0.3457	......[Z]	0.7384
Rep	3	0.3393	0.6642	0.5948	0.4287	0.4651	0.1534	......	0.9115
Rep×irrigation (irrig)	6	0.6023	0.2485	0.7586	0.4848	0.4233	0.0609	......	0.2951
Soilamd[X]	1	0.0181**	0.1786	0.3022	0.9309	0.3618	0.5611	......	0.9409
Rotation[Y]	1	0.2547	0.1191	0.2823	0.2579	0.1564	0.1621	......	0.9100
Irrig×Soilamd	2	0.0181**	0.1761	0.9171	0.1991	0.5831	0.2180	......	0.1667
Irrig×rotation(rot)	2	0.2181	0.4680	0.8877	0.2955	0.2663	0.2964	......	0.0739
Irrig×soilamd×rot	2	0.5251	0.4736	0.5677	0.4214	0.2746	0.1952	......	0.4969
		Black scurf		Silver scurf		Black dot		Common scab	
Source of variation	df	1996	1997	1996	1997	1996	1997	1996	1997
Irrigation x soil management (1996-1997)									
Irrigation[W]	1	0.7800	0.9157	0.6450	0.0475*	0.8200	0.8959	0.3526	0.0169*
Rep	3	0.6989	0.7733	0.2001	0.1244	0.3371	0.7165	0.9277	0.1646
Rep×irrigation (irrig)	3	0.2032	0.1189	0.0654	0.1354	0.1300	0.4017	0.8651	0.1128
Soilamd[X]	1	0.5025	0.3416	0.2619	0.0546*	0.0012**	0.0577*	0.9490	0.0001**
Rotation[Y]	1	0.1476	0.1770	0.2294	0.0010**	0.2271	0.0435*	0.2850	0.1900
Irrig×soilamd	1	0.2470	0.3226	0.9933	0.0453*	0.0510*	0.7815	0.5009	0.2401
Irrig×rotation (rot)	1	0.2701	0.8897	0.2019	0.0494*	0.2029	0.0271*	0.1105	0.1383
Irrig×soilamd×rot	1	0.5705	0.8002	0.1946	0.8006	0.2980	0.1952	0.4187	0.9841

[W]Irrigation treatments consisted of un-irrigation, best and reduced irrigation (1994-95); irrigated and un-irrigated (1996-97). [X]Soil amendment treatments consisted of grain+manure+compost and green manure+manure+compost (1994-1995). In 1996-1997, soil was amended (manure+compost) or not amended. [Y]The rotations were small grain (oats) and green manure crop (oats, peas and vetch). [Z]Data could not be analyzed due to very low or zero disease values. * and ** refer to significant at p<0.05 and 01, respectively

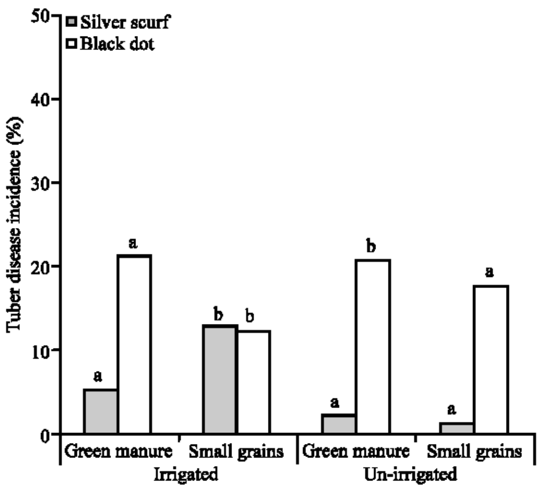

Fig. 3: The effects of supplemental irrigation and crop rotation interactions on percent incidence of tuber diseases in 1997. Crop rotation consisted of green manure (vetch/peas/oats) or small grains (oats) and the plots were either irrigated or had no water applied to field plots (un-irrigated check) and planted with potato cultivar Superior . Different letters for each tuber disease between rotation within irrigation treatment indicate significant differences (p<0.05) based on Fisher's LSD statistics

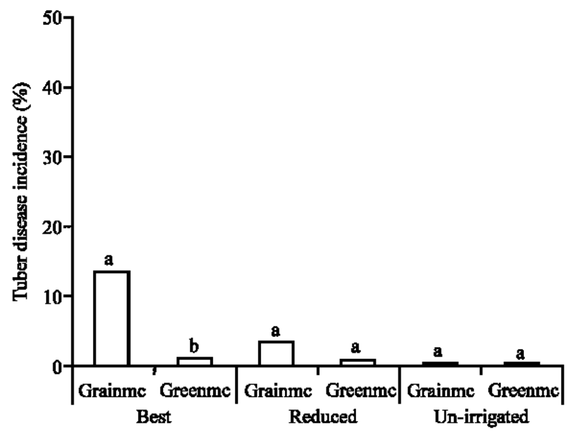

Fig. 4: The effects of soil amendment on percent incidence of black scurf disease on potato cultivar Superior in 1994. Grainmc refer to amendment of grain+manure+compost while Greenmc refer to Green manure crop (vetch/pea/oat)+ manure+compost added as amendments to field plots in 1994. Best irrigation refers to water applied to maintain optimum plant and soil water availability, based on gypsum blocks and tensiometer readings. In reduced irrigation, water was applied to field plots from tuber initiation to mid-bulking with a goal of maintaining 50% PAW. Un-irrigated or check treatment had no water applied to field plots. Different letters for tuber disease between amendment within irrigation treatment indicate significant differences (p<0.05) based on Fisher's LSD statistics

Irrigation by soil amendment effects on potato tuber diseases: The interaction of irrigation treatment x soil amendment was significant for black scurf incidence in 1994, where best irrigation treatment was used (Fig. 4) and

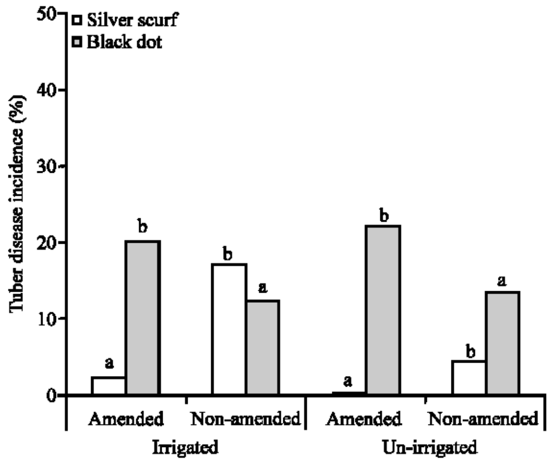

Fig. 5: The interaction effects of supplemental irrigation and soil amendment (1997) on percent incidence of tuber diseases. Disease incidence was quantified on the cultivar Superior. Amended plots had manure + compost and non-amended plots had no amendments. Irrigated plots had water and un-irrigated treatment had no water applied. Different letters for tuber disease between amendments and within irrigation refer to significant differences in disease incidence ($p<0.05$) based on Fisher's LSD statistics

for silver scurf and black dot in 1997 (Fig. 5). Black scurf incidence was significantly greater under amendment of grain+manure+compost (grainmc) than on green manure+manure+compost amendment (greenmc). Silver scurf incidence was consistently greater in amended compared to non-amended plots under irrigated and un-irrigated treatments, while black dot was lower in amended than non-amended plots irrespective of irrigation treatments (Fig. 5).

DISCUSSION

Irrigation treatments had variable effects on soil-borne diseases across years and treatments. This suggests that water application may enhance conditions suitable for increases in the incidence of selective tuber diseases or not at all. Previous research showed that lower temperatures and increased soil moisture are favorable for stem canker infection (Hide and Firmager, 1989). Overhead irrigation experiments have been reported to alter potato canopy microclimate and, thereby, affect disease development (Adams and Stevenson, 1990). The variation in the incidence of black scurf disease observed in this study implies that the timing and frequency of irrigation application may influence soil moisture conditions conducive for pathogen infection and disease development.

The effects of irrigation treatments on black dot incidence on tubers varied among irrigation treatments and years. This suggests that irrigation applications may affect black dot development depending on the treatment and timing of water application. In a previous research, water application early in the season was noted to decrease infection of potato plants and tubers by the black dot pathogen (Read and Hide, 1988). This was attributed to excessive soil moisture for fungal growth and infection. Moderate soil moisture was also noted to be conducive for black dot infection and disease development. Adams and Stevenson (1990) also showed that excessive soil moisture may affect potato tubers and lead to swollen lenticels and increased susceptibility to tuber-borne infections. Additionally, overhead irrigation and microclimate have been reported to affect black dot development on potato, depending on the initiation of irrigation application relative to crop growth period (Raniere and Crossan, 1959; Adams *et al.*, 1987). In this study, variation on irrigation effects on disease was noted, even though black dot levels were higher than other diseases. Because we did not quantify if there were any differences in pathogen density in soils in the various field plots as well as possible variation in virulence among pathogen strains between and within plots and years, it is difficult to mention what the precise effects of tuber disease variation could be attributed to exactly. The effect of irrigation treatments on plant diseases has also been attributed to conducive micro-climatic conditions in the potato canopy leading to increased disease levels. Therefore, the significance of the interactions of irrigation treatment x year for *R. solani* suggests that treatment effects varied among irrigation applications and years, perhaps due to microclimatic effects.

Crop rotation in the presence of irrigation applications did not significantly affect the incidence of black scurf, except under best irrigation. The lack of significant differences in the incidence of black scurf between the rotation treatments under reduced and un-irrigated treatments suggests that the rotation crops under investigation may be of limited use for *R. solani* control under those conditions. It is also possible that due to the wide host-range and saprophytic colonization of *R. solani*, fungal survival as sclerotia on tubers and in soil, or other plants is possible. In this experiment, soil-borne inoculum was not quantified, so it is possible that inoculum levels could have been low for significant disease effects to occur under the above mentioned irrigation treatments. This is in contrast to the field studies conducted by Frank and Murphy (2001) and

Larkin and Honeycutt (2006); who observed that crop rotations or cover crops can significantly affect Rhizoctonia diseases consistently in potato-based cropping systems. The influence of cropping sequences in the absence of irrigation treatments on soil-borne pathogen populations have also been demonstrated for *Verticillium dahliae* and *R. solani*, in which certain rotations were more effective for disease control, while others were not effective (Davis and McDole, 1979; Larkin and Honeycutt, 2006).

Although differences in the incidence of black dot were observed among rotation treatments under irrigation, these differences were significant only in some years. This suggests that rotation crops may result in variable disease levels. *C. coccodes* is a secondary pathogen and often associated with senescening potato plants. Therefore, crop rotation and other methods designed to reduce soil-borne inoculum of *C. coccodes* may have a limitation. Our findings are in contrast to that of previous researchers. Scholte *et al.* (1985) observed that the incidence of black dot and other potato diseases were reduced in short rotation crops. Crop rotation has been shown to reduce soil-borne inoculum due to non-host rotations (Larkin and Honeycutt, 2006). However, because crop rotation was used in conjunction with irrigation treatments, our results may differ from previous studies due to the added moisture components. The pathogen can also be easily introduced on seed tubers which could impact disease levels in subsequent cropping years (Read and Hide, 1988).

Similarly, the effect of crop rotation resulted in differences in the incidence of silver scurf on tubers in certain years. This suggests that green manure (peas/vetch/oats) and small grain (oats) rotations may differentially impact *H. solani* fungal propagules under irrigated experimental conditions. Based on our results in which multiple pathogens were detected on potato tubers, it is also possible that there may have been competition or antagonism between *H. solani* and *C. coccodes*, or other pathogens since the presence of one pathogen on tubers appears to limit the incidence of the other pathogen on tubers. *H. solani* have been shown to have a limited host range and impacted by other soil-borne pathogens (Errampalli *et al*., 2001a, b).

Variation in tuber diseases was detected among soil amendments for selective tuber diseases across years. This suggests addition of soil amendments may selectively affect some of the tuber diseases examined. Soil amendments have been shown to affect or decrease incidence and severity of soil-borne diseases due to increased microbial activity (Larkin and Honeycutt, 2006). It is likely that a similar mechanism may be a contributing factor for decreases in the incidence of some tuber-borne diseases. The significant interactions of soil amendments by irrigation on some tuber diseases imply that supplemental irrigation may modify foliar or soil microclimate, which may be favorable or detriment to some of the soil-borne pathogens.

We conclude that supplemental irrigation, crop rotation and addition of soil amendments affected the incidence of some potato tuber diseases. While crop rotation may reduce soil-borne propagule build-up by removal or reduction of susceptible host crops, soil amendment may enhance microbial competition or modify soil environment to the detriment of tuber pathogen or diseases. Disease increases may be aggravated by soil moisture conditions, but soil moisture may also be limiting for some tuber diseases. The timing and frequency of irrigation in relation to tuber initiation and tuber disease onset appears to be one of the factors determining tuber disease development. Although the pathogen strains, population density and virulence were not examined, those factors may influence development of potato tuber diseases. The frequent changes in pathogen composition and virulence over time, suggests that disease development and incidence may actually differ between years or from the period when assessment were made. Therefore, future studies should focus on these comparisons of management systems and their interactions in the light of changing pathogen composition or virulence and justifies the need for future investigations.

Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation for endorsement by the US Department of Agriculture or the University of Maine.

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