Chapter 5
Comparing Modelled Productivity to Historical Data in New England Potato Production Systems

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Abstract Potato yields in Northern Maine have remained fairly constant for the last 70 years. Many long-term projects have sought to identify the limitations to potato yield, but identifying limiting factors is difficult without first identifying the upper limits of potato production. A simple, light-driven mechanistic model is validated with specific case studies, and then, potential yield limitations to potato production in this region are identified based on analysis of the model. It was found that meteorologically-limited productivity peaks at about 55 Mg ha^{-1}, which is about 80% higher than historical averages. Most yield increases in those specific case studies examined were due to enhancement of radiation capture, which was achievable either by improved water management or disease suppression. Strategies for sustained yield improvements should continue to improve on radiation capture, either by increasing the peak radiation capture potential, prolonging the radiation capture duration, or by shifting radiation capture to coincide with available light. This model is useful to set realistic productivity goals for this region, can be easily adapted to other regions, and indicates strategies for potato yield improvement.

5.1 Introduction

Northern Maine, the primary potato production area in the New England region, has a climate with average temperatures ideally suited for potato production (16.8–18.6°C average temperature from June to August; C.I.A 2011), ample rainfall

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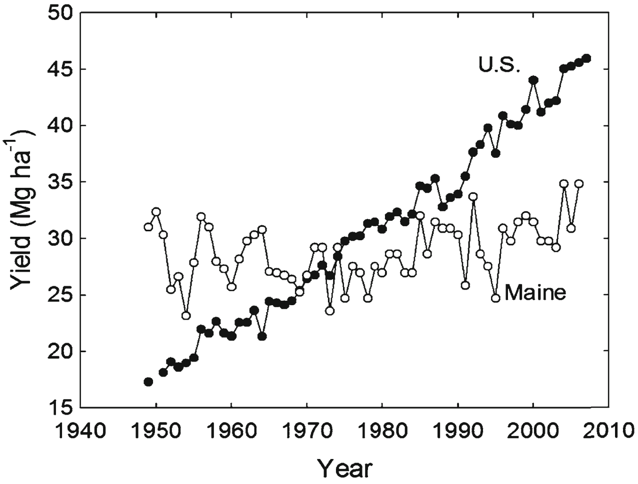

Fig. 5.1 Average potato yield from 1949 to 2008 in the US and Maine. Data are adapted from USDA National Agricultural Statistics Services (2011a, b)

(930 mm year^{-1} average), and a growing season of between 100 and 110 days. These characteristics allowed Maine to have a strong potato industry, relative to other US states, since 1870 (USDA National Agricultural Statistics Services 2011b). Today, Maine remains in the top ten producing states in the U.S. (USDA National Agricultural Statistics Services 2011a), in spite of yield rates that have remained fairly constant for the last 70 years (Fig. 5.1). The lack of improvement in potato yields per area over the last seven decades even suggests that some upper limit may have already been reached. How much can possibly be produced in this region – or any region?

There are many environmental factors that could be limiting potato production. Cool air and soil temperatures early in the season may delay shoot emergence. Whereas total rainfall amounts are often adequate over the course of a growing season, uneven distribution of rainfall can lead to flood or drought stress. Long periods of humidity, rain events, and cool temperatures can exacerbate foliar disease pressure including late blight (Olanya et al. 2007, 2010). On average, there are over 160 days per year with measurable precipitation (at least 2.5 mm), which decreases potential sunlight (C.I.A 2011). Long-term potato culture with historically little crop rotations has depleted the soil organic matter, which altered water and nutrient holding dynamics (Carter and Sanderson 2001; Griffin and Porter 2004). Late spring freeze events or even snowfall can delay field planting shortening the growing season.

In the simplest terms, potatoes must intercept sunlight in order to photosynthesize, and transfer that fixed carbon efficiently to the tubers. Stress in the early canopy development can negatively influence leaf expansion and leaf emergence, or can impact photosynthesis once the leaves have emerged or the canopy has formed. Weed competition and insect and disease pressure can impact both the plant's ability to gather light and partition resources efficiently to expanding tubers, potentially reducing yield. Finally, stress later in the crop production cycle can negatively influence tuber initiation and expansion, or shift resources from tubers to other plant parts to, for example, explore the soil for water and nutrients.

Several long-term projects have sought to identify the limitations to potato yield and improve management practices in ways that boost potato yield. But it is difficult to identify the limitations to potato yield without first identifying the upper limits of potato production (Bugbee and Salisbury 1988).

This chapter seeks to describe the theoretical limits of potato productivity in this region through a simple, light-driven model. The goal in the initial modelling is to illustrate where the upper limit to potato productivity might be if conditions were ideal. This approach was successfully demonstrated in the Estonian region for potato production (Kadaja and Tooming 2004). Then, from the ideal production levels, we work backwards to predict the yields of several specific case studies in an effort to identify some additional yield limitations to potato production in this region. Case studies of both state-wide production and smaller-scale field plots are compared to the model to see how further improvements might be made. This assessment would help identify parameters that should be measured more often in the field.

5.2 Field Site and Model Conceptual Description

A detailed description of the research site and management can be found in Larkin et al. (2011). Briefly, the research plots are located in Presque Isle, Maine on Caribou-type soil. There are five crop management systems: SQ is status quo and represents a 2-year barley-potato rotation; PP is a potato monoculture (no rotation); DS is disease suppressive, which includes a 3-year rotation of mustard green manure, Sudangrass green manure, and winter rye-potato; SC is soil conserving, which is a 3-year rotation of no-till barley interseeded with timothy, timothy sod, and potato; and SI is soil improving, which builds upon the SC treatment by adding compost in each phase of the rotation. Each treatment is grown under rainfed (unirrigated) and irrigated conditions. Irrigation treatments are applied based on the average of 20 tensiometers located throughout the research site. 17.5 mm of water is applied at each irrigation for those treatments. Fertilization is based on pre-plant soil tests each season. Planting times at the research site range from May 24 to June 1, and tend to be a week to 10 days later than commercial fields in the same area. Unirrigated plots are replicated six times and irrigated plots are replicated five times.

There are many models for potato production that can reliably replicate field data in a variety of production systems (e.g. POMOD, Kadaja and Tooming 2004; SPUDSIM, Fleisher et al. 2010; SUBSTOR-potato, Ritchie et al. 1995; SIMPOTATO, Hodges et al. 1992). Their detail and complexity have allowed for comprehensive analyses of mechanisms of stress and steady-state production, in part due to their ability to accept site, cultivar, and management-specific parameters.

As early as three decades ago, Monteith (1977) proposed a simple, light-driven model that could estimate yield potential in an area given few inputs. This model has been modified and adapted since its development and includes an "Energy Cascade" model useful for controlled environment studies (Volk et al. 1995). Conceptually, the energy from light "flows" through various efficiencies such as radiation capture efficiency, photosynthetic efficiency, respiration efficiency, and partitioning efficiency until a yield per area is calculated. Mathematically, yield is calculated in this model as:

$$\text{Yield}\,(\text{g yield}/\text{d}/\text{m}^2) = \text{PPF} \times \text{RCE} \times \text{CQY} \times \text{CUE} \times \text{HI} \times \text{CF}$$

Where PPF is photosynthetic photon flux (moles photons available/d/m^2), RCE is radiation capture efficiency (moles photons absorbed/moles photons available), CQY is canopy quantum yield (moles C fixed/moles photons absorbed), CUE is carbon use efficiency (moles C remaining in plant/moles C fixed), HI is harvest index (moles C harvested/moles C remaining in plant), and CF is a conversion factor that takes into account C content of tubers and percent dry weight (g yield/ mole C harvested). The model is run in 1-day time steps, and the sum of the daily values is the total yield. These parameters can either be measured directly or calculated from direct measurements. Additionally, the model lends itself to expansion for more mechanistic analysis, as sub-models addressing each parameter are developed, feeding into the main model's equation.

5.3 Description of Model Parameters

Idealized PPF was determined based on location latitude from the plant growth model PlantMod (version 4.0.7, IMJ Software). Idealized PPF is the PPF with no cloud cover, so the more cloud-bearing weather events a site has, the more this term would over-estimate actual PPF (Table 5.1).

Typical PPF was obtained from a 30-year historical weather dataset (Marion and Urban 1995). This dataset is not average values for a period of time, but typical or representative values for that date and time at a given location, in this case, Caribou, ME approximately 10 km north of the field site. An example set of data may utilize data from Feb. 1987 followed by Mar. 1982 because these months were deemed most representative of the weather at that location (Marion and Urban 1995). The value of this, as opposed to using averages, is that day-to-day light fluctuations are simulated. A single day's simulation, therefore, may not accurately predict that day every year, but simulations over longer periods of time would likely predict that site with reasonable precision yet show typical variability from month to month or week to week that can be expected at that location. Actual PPF was calculated based on radiation measurements from a weather station located adjacent to the research plots in Presque Isle, Maine. A pyranometer (model 200X, LI-COR, Lincoln, NE) measured total W m^{-2} every minute and the average of 10 min was stored. It was empirically determined that approximately 48.3% of the measured radiation from

Table 5.1 Model parameters and the values utilized for Idealized, Typical, and Actual scenarios

	Modeling scenario		
	Idealized	Typical	Actual
PPF (mol supplied m^{-2} day^{-1})	Light data obtained from PlantMod 4.0.7 assuming no clouds during the production season	Light data from 30-year database describing typical radiation at the field site	Measured light data at the field site for each year
RCE (mol captured/mol supplied)	Highest possible from measured canopies, pooled over 4 years	Highest possible from measured canopies, pooled over 4 years	Measured from each year and each treatment
CQY (mol C fixed/mol captured)	0.03	0.03	0.03
CUE (mol C in plant/mol C fixed)	0.6	0.6	0.6
HI (mol C in harvestable yield/mol C in plant)	0.8	0.8	0.8
CF (g fresh weight/mol C in harvestable yield)	(30 g potato/mol C harvested in tubers)/0.8 water content	(30 g potato/mol C harvested in tubers)/0.8 water content	(30 g potato/mol C harvested in tubers)/0.8 water content

PPF photosynthetic photon flux, *RCE* radiation capture efficiency, *CQY* canopy quantum yield, *CUE* carbon use efficiency, *HI* harvest index, *CF* conversion factor

that pyranometer was in the 400–700 nm range, so radiation measurements were converted to PPF using $2.07 \times W\ m^{-2} = \mu mol\ m^{-2}\ s^{-1}$ (1/0.483 = 2.07; this is a site and/or sensor-specific conversion but is expected to be a reasonable estimate of other sites; see also discussion in Nobel 1991). These instantaneous values were converted to the proper units by multiplying by 3600 $s\,h^{-1}$/1,000,000 $\mu mol\ mol^{-1}$. Together, the Idealized, Typical, and Actual model simulations are based on these PPF datasets to provide an optimized, realistic, and actual view of PPF at a given site. The names of these model simulations refer only to the PPF, not necessarily to the selection of other model terms (Table 5.1).

RCE can be estimated on wide spatial scales non-destructively by photographic image analysis (Klassen et al. 2003) or spectroscopic analysis that correlates canopy N-content with light capture (Major et al. 2003). In our case, RCE was determined from weekly light measurements made throughout the production seasons over 4 years of field experiments. The measurements were made with a line quantum sensor (SunScan, Delta-T Devices, Cambridge, UK) that accounts for intercepted and reflected radiation based on canopy characteristics and light measurements above and below the potato canopy. Four years of weekly RCE measurements were pooled and for the Idealized and Typical modelling scenarios (Table 5.1), the pooled values were the highest RCE values for a given day after emergence, which developed a maximum RCE throughout the growing season. The peak RCE would occur if there were no canopy disturbances that occurred due to intermittent drought, herbivory, wind or other disturbances. RCE in individual years were used to evaluate more real-world production scenarios in the Actual modelling scenarios that would include management-specific canopy disturbances.

CQY is a more difficult parameter to measure directly in the field, and only a few measurements have ever been made on whole potato plants or communities (Timlin et al. 2006; Fleisher et al. 2006). Fortunately, CQY varies in predictable ways for C_3 plants and reasonably accurate estimates can be made based on a few known environmental conditions (Long 1991). Photosynthetic efficiency varies with temperature and CO_2 concentration. The peak efficiencies reported for C_3 plants vary from a ratio of 1 CO_2 fixed for every 8 photons of light (quantum efficiency of 0.125 moles CO_2 fixed per mole photons absorbed; Thornley and Johnson 1990) to 1 CO_2 fixed for every 12 photons (quantum efficiency of 0.083 moles CO_2 fixed per mole photons absorbed; Lal and Edwards 1995). In a model for a typical C3 plant, Harley and Tenhunen (1991) assumed a value of 0.06 mol mol^{-1}, whereas Björkman (1981) report a similar value in C_3 plants over a range of temperatures from 20°C to 30°C. High light, such as that found at the tops of canopies, and high temperatures decrease quantum yield in ambient CO_2 concentrations (about 400 μmol mol^{-1} CO_2). In a canopy-scale study of potato photosynthesis, Fleisher et al. (2006) report peak CQY values of above 0.1 mol mol^{-1} in low light and temperatures. In higher light and temperatures, values were measured in the 0.013–0.038 mol mol^{-1} range. We therefore assumed a CQY value of 0.03 mol mol^{-1} for this model, which closely matches those values found by Fleisher et al. (2006) in similar light and temperature environments. Small changes in the value of this term (for example, 0.03–0.04) lead to large changes (in this example, 25% greater) in the overall predictions, and it is for this reason that this term is not modified among simulations since it is based on lab measurements of potato.

CUE is a calculated term that describes the amount of carbon incorporated into the plants divided by the total amount of carbon fixed in photosynthesis. Essentially, it is a term describing how well plants can incorporate the carbon fixed during the day into biomass gain. It requires accurate measurements of canopy net photosynthesis, and night respiration. Because day-time respiration cannot be measured directly, day-time respiration is estimated as some percentage of night-time respiration corrected for changes in day-night temperature. Many estimates of this parameter have been made on a variety of plants grown in different environments. Laboratory measurements tend to be slightly higher than field measurements, but the overall range of CUE reported is 0.50–0.65 in steady-state or actively growing conditions (Gifford 1994, 1995; Frantz et al. 2004). Lower values have been measured for seedlings or in low growth rates due to stressful environments (van Iersel 2003b). Overall, this term is less well studied compared to other parameters within this model. We used a value of 0.60 for this model to reflect healthy, field-grown plants (Gifford 1995).

HI is measured by harvesting the plant at the end of the experiments, weighing tubers separately from the shoot and non-tuberous roots. If, at the end of an experiment the HI is a value of 0.8 (80% of the mass is in the tubers), it can be assumed for simplicity for each day that 80% of retained carbon is partitioned into the tubers.

This would not be the case if yield was to be predicted throughout the growing season as many other conditions can influence HI such as temperature, stage in growth, genetics, N supply, water, light, etc. Potato HI has been reported to be between 0.2 and 0.8, with lower values found in higher temperature environments (Fleisher et al. 2006; Tibbitts et al. 1994). We used a value of 0.8 for this model to reflect HI typically found in lab-based studies performed at the temperatures commonly encountered during field production in this region.

Finally, a conversion factor (CF) is used to convert moles of carbon in potatoes to grams dry weight yield. Since potatoes are predominantly starch and other carbohydrates (Kolbe and Stephen-Beckman 1997), a conversion factor of 30 g/mol harvested potato tubers is used. Potatoes are assumed to be 80% moisture, based on previous reports (Tibbitts et al. 1994; Kolbe and Stephen-Beckman 1997).

5.4 Overall Model Performance

Overall, the model over-predicted yield in five distinct management systems by, on average, 1.4 Mg ha^{-1} (Fig. 5.2). However, the model adequately described the year-to-year variation. This is not in itself surprising since the primary drivers for the

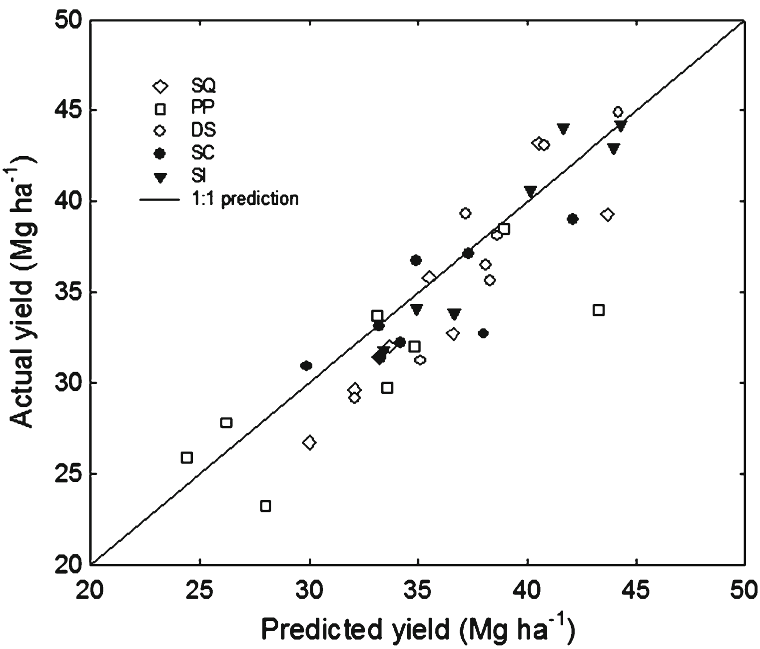

Fig. 5.2 Comparison of predicted (modelled) and actual (measured) yield in the five potato management systems. In general, the model over-estimated the yield by an average of 1.4 Mg ha^{-1}, perhaps due to differences in harvest index, carbon use efficiency, and/or canopy quantum yield

model, light and light capture, were measured directly in each management system. However, it does speak to the reasonableness of the other, estimated parameters such as CQY, HI, and CUE. It has been observed that models using a RCE approach tend to over-estimate the yield perhaps due to the differences in quantum yield among different leaf layers (Fleisher et al. 2010). This effect should have been minimized since estimates of CQY were made not from biochemical or leaf-scale models, but on whole-canopy measurements. The over-prediction likely resulted from small errors in overestimating CQY, CUE, and/or HI. Each parameter was selected based on published reports of plant canopies and, where possible, potato plant communities. CQY value of 0.03 is half the value used in other plant community models (Harley and Tenhunen 1991) and is less than the peak CQY reported in potato canopy studies previously (Fleisher et al. 2006). CUE and HI values of 0.6 and 0.8, respectively, were selected as the highest reported values of potato plants or plants in general in the temperature, CO_2, and light ranges encountered in these field plots. However, many of those reports were based on controlled environment conditions rather than in the field. It is feasible that both CUE and HI would decline slightly in field conditions given less-than-ideal conditions (Nemali and van Iersel 2004; van Iersel 2003a) from water, temperature, insect, or disease stress. These stresses occurred to varying degrees in the different management environments, likely contributing to the discrepancies in predicted versus actual yields in the different treatments. The sporadic nature of stress events make parameterizing a model based on controlled environment studies challenging with potatoes. For example, a single, short-term drought event during tuber bulking can inhibit future bulking of those potatoes and result in initiation of new tubers. These not only decrease potato grade but lower overall yields, which would show up as decreased HI in this model.

5.5 Results of the Measured and Modelled Productivities at the Field Experiments

In the idealized (i.e. no clouds) simulation, the upper limit for potato productivity was predicted to be 85.0 Mg ha^{-1}, which is about 70% greater than top reported yields in the area (Table 5.2) and 180% greater than historical averages (Fig. 5.1). A yield of 85.0 Mg ha^{-1} represents the upper yield limit for potato if there were no clouds and RCE was maximized for the entire growing season at this location.

Utilizing typical weather patterns from the 30-year historical record, which incorporates cloudy conditions typically found in a potato growing season in this area, the maximum potential yield is 55.5 Mg ha^{-1} or 10% greater than maximum measured yields and 80% greater than historical averages (Table 5.2). In other words, best-case yields utilizing realistic weather from Northern Maine represent significant gains above historical averages and have nearly been achieved in small areas on commercial farms in some years. Utilizing actual weather recorded during 2006–2009 and starting with planting dates from those years, the best case yields (maximum RCE) would have been 52.7, 55.8, 49.2, and 58.3 Mg ha^{-1}in a rainfed,

Table 5.2 Potential and measured potato yields in northern Maine

	Potential	Measured
	Mg ha^{-1}	
Maximum	85.0	50.5
Typical climate	55.5	30.9
2006 climate	52.7	34.3
2007 climate	55.8	33.1
2008 climate	49.2	30.3
2009 climate	58.3	30.9

For all potential values, peak radiation capture measured throughout growing seasons over a 4-year period was used. For potential maximum yield, theoretical light based on latitude and no cloud cover was used, while typical climate used historical averages for climate including sunlight to predict upper limit of yield. Maximum measured yield has been observed on smaller areas of commercial farms but has been difficult to reach consistently on large-scale production

SQ management system most similar to industry standards in this region. These yields compare favourably with the yields predicted from the "typical" weather dataset, indicating that as a reference, the typical weather provides realistic conditions for simulation over the course of a potato growing season at this location. The simulated yields compare to reported state-wide averages of 34.3, 33.1, 30.3, and 30.9 Mg ha^{-1} in 2006–2009 respectively (Table 5.2). The differences in yields for the different years are likely due to differences in radiation capture from year to year compared to the optimal RCE that should be possible if no stress is experienced.

If actual radiation capture from those years are used, our predicted yields were 35.5 ± 3.6 Mg ha^{-1}, 33.2 ± 4.6 Mg ha^{-1}, 32.1 ± 1.9 Mg ha^{-1}, and 30.0 ± 0.9 Mg ha^{-1}. Actual yield was 35.8, 31.4, 29.6, and 26.7 Mg ha^{-1} (SQ treatment; Fig. 5.3). Altering management can significantly influence yields of potatoes. Continuous potato production results in lower yield, with less measured radiation capture in this treatment (Figs. 5.3 and 5.4). Managing the soil system to increase resiliency against diseases improves yield above the barley-potato rotation (DS treatment, Fig. 5.3). Reduction of foliar diseases would result in more radiation capture, increasing yield, while reduced root diseases could limit water stress and wilting or direct loss of potatoes. SC and SI treatments also boost yield above the barley-potato rotation, likely due to improvements in water availability and, therefore, reduction in water stress during periods of drought (Fig. 5.3; Porter et al. 1999).

Adding irrigation tends to boost yield, especially in years with less rain or infrequent rain events (Fig. 5.5). Much of the variability in yields among the management strategies could be attributed to radiation capture differences (Fig. 5.4). The largest difference between irrigated and rainfed plants is the radiation capture throughout the season; with irrigation, leaves intercept more light. This could be due to more leaves, larger leaves, or properly oriented leaves (turgid versus wilted) to collect the available light. Peak radiation capture measured in traditional barley-potato plots in unirrigated areas was 81% ± 6%, while the peak capture in

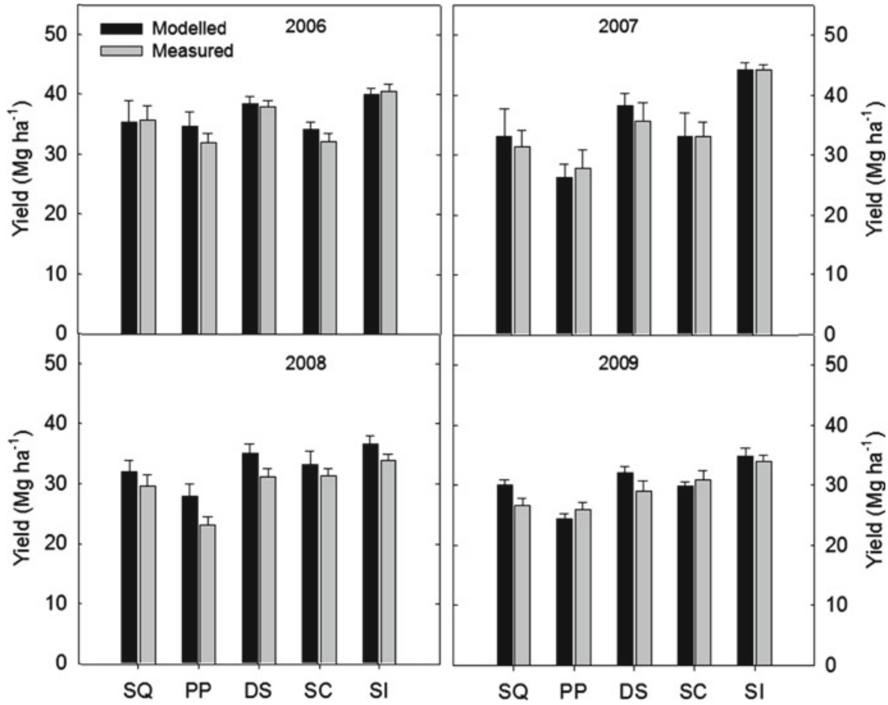

Fig. 5.3 Measured and modelled yields in rainfed field plots managed in different ways for 2006–2009. SQ is status quo barley-potato rotation, PP is continuous potato-potato production, DS is disease suppressive, SC is soil conserving, and SI is soil improving. Mean yield values are shown with standard errors (n = 6)

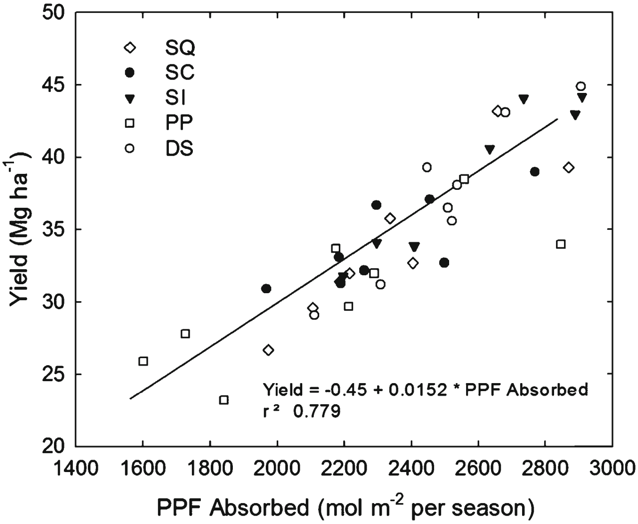

Fig. 5.4 The relationship between PPF (photosynthetic photon flux) absorption and yield of potatoes from 2006 to 2009. SQ is status quo barley-potato rotation, PP is continuous potato-potato production, DS is disease suppressive, SC is soil conserving, and SI is soil improving. Data were collected by taking weekly radiation capture measurements and calculating the fraction of available light absorbed throughout each growing season

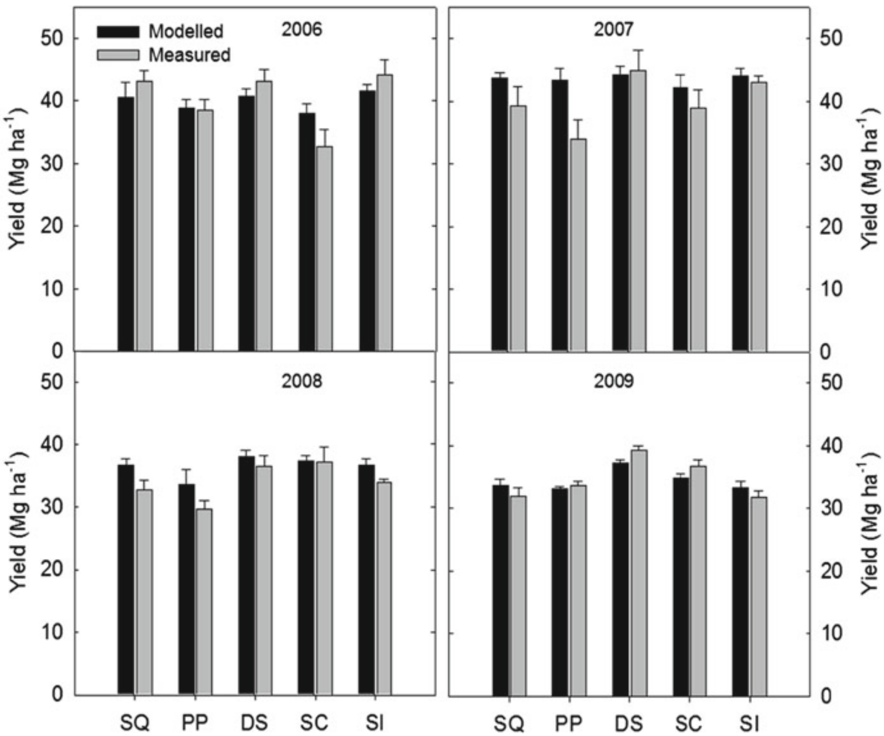

Fig. 5.5 Measured and modelled yields in irrigated field plots managed in different ways for 2006–2009. SQ is status quo barley-potato rotation, PP is constant potato-potato production, DS is disease suppressive, SC is soil conserving, and SI is soil improving. Mean yield values are shown with standard errors (n = 5)

irrigated plots was 94% ± 3%. This resulted in predicted yield of 40.5 ± 2.5 Mg ha^{-1} due to improved radiation capture. Measured yield in those plots was actually 43.2 Mg ha^{-1}, indicating that the increase in yield was due in part, but not exclusively, to improved radiation capture of the canopy.

5.6 What Does the Model Tell Us About Improving Yields Based on the PPF Component of the Model?

Comparing theoretical peak yields to actual yield or predicted yield using real-time weather information suggests some strategies for improving yields. The fact that yield predictions were so close to measured yield when measured PPF and RCE values were used to simulate 2006–2009 seasons strongly indicates the assumed values of CQY, HI, and CUE were reasonable. If values for HI and CUE used in the model are within 0–5% of actual HI and CUE in the field, then the most likely target for improved production is enhancing radiation capture. This can be done by (1) improving the peak radiation capture potential, (2) improving the duration that the peak radiation capture is maintained, (3) by enhancing the light that reaches the canopy, or (4) by a combination of these.

Increasing the peak radiation capture is done by ensuring proper spacing within and between rows to balance maximum resource (light, water, and nutrients) capture for individual plants and minimizing plant-to-plant competition. Recommendations for spacing and resource application have been developed and, for the most part, optimized for this production area.

Irrigation and/or soil management techniques that improve water and nutrient availability have clearly been demonstrated to improve yield in large part due to enhanced radiation capture over the season (Figs. 5.3 and 5.5), which is consistent with Porter et al. (1999). Improved recommendations for the frequency and amounts of green manures or compost to be incorporated into a field will help determine the economic cost/benefit of these strategies so that more growers can take advantage of the clear benefits from these practices. Currently, only about 20% of commercial fields in this region are equipped to irrigate their fields on a regular basis. The costs of meeting regulatory requirements for capturing and using water have proven to be a large inhibition to more widespread use of irrigation in potato fields. A combination of organically-derived soil amendments and irrigation holds the most promise for effectively maximizing radiation capture for the duration of the growing season.

Insect, weed, and disease avoidance would also effectively improve the radiation capture since those stresses can decrease leaf area or create conditions that limit light reaching the canopy. Soil management that targets the reduction of disease has also been shown to minimize crop losses (Larkin and Griffin 2007), and improve yields in part due to enhanced radiation capture (Figs. 5.2 and 5.4). It is important to note that changes in soil or water management can shift the disease risk from one threat to another (Olanya et al. 2010).

It is often said that potato yield in the New England area is limited due to a short growing season. Comparing available light with radiation capture of the potato canopy (Fig. 5.6), it can clearly be seen that the weather-limiting problem has as much to do with crop timing (occurrence during the year) as it does the length of the growing season. Predicted potential PPF ranges from 65 mol m^{-2} day^{-1} to 68 mol day^{-1} from emergence to the Summer Solstice. After that time, PPF steadily declines until harvest, when predicted PPF reaches about 40 mol m^{-2} day^{-1} in early October. At the Summer Solstice, the plants have just emerged, so only about 5% to 10% has been measured to be absorbed, with the variation due to differences in planting date. When the plant has produced a canopy to intercept light, the summer solstice has already been reached. In other words, the peak light environment occurs when there is no canopy to intercept the light, and when the canopy is present, potential light is declining. This makes late-season cloudy days or rain events especially damaging because there are fewer days with less light to compensate for the lost light. Selecting varieties that can emerge in cooler soil conditions or perhaps pre-treating the seeds with a longer dormancy breaking period after cold storage are, theoretically, approaches to improve early potato stand establishment. This model predicts a 10% and 17% increase in yield if planting could occur 2 and 4 weeks earlier in the

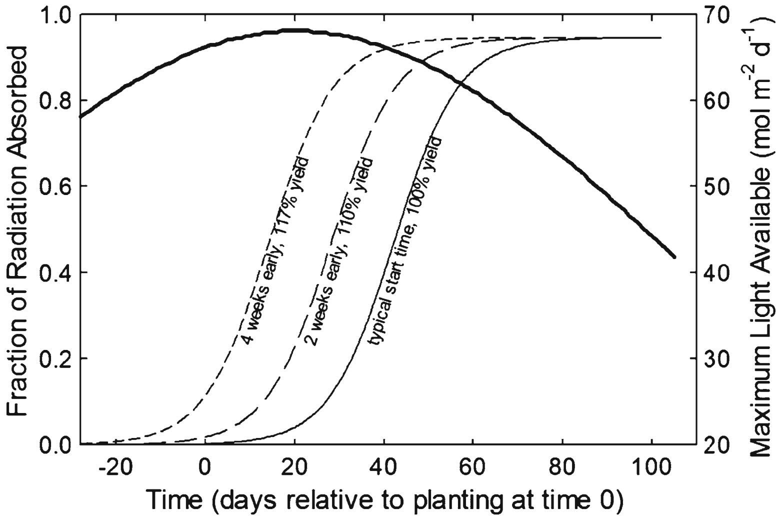

Fig. 5.6 Available light (thick line, right axis) and optimized radiation capture (thin line, right axis) throughout a potato growing season. In a typical year, only 5% to 10% of peak light at the summer solstice is captured due to a later planting time or delayed emergence. Planting 2 (long-dashed line) or 4 weeks earlier (short-dashed line) better captures more light so that yield can be improved by up to 17% over the same growing season length

season, respectively, with no additional days of growth. In other words, without changing the length of the season but when the season occurs, it is possible that significant yield improvements could be made. However, getting into wet fields early in the planting season remains a significant engineering hurdle to overcome in order to plant earlier and avoid soil compaction. Late season frost is still an issue as well with earlier emerging varieties.

Yield was strongly correlated with radiation capture (Fig. 5.4) and some management strategies improved radiation capture. For example, irrigation consistently increased yields due to higher peak radiation capture; avoidance of drought led to fewer wilting or senescing leaves that would intercept little light. Higher disease pressure in continuous potato cultivation was a likely cause of decreased radiation capture (Fig. 5.4), while the disease suppressive system had less loss of canopy from disease and corresponding increases in yield. Finally, the soil improving system, with additions of compost as a cornerstone to the management strategy, had consistent radiation capture between irrigated and unirrigated treatments. This suggests that the compost helped maintain moisture availability throughout each season, thereby avoiding wilting or periodic water stress encountered in the other, rainfed systems.

There is a general lack of measurements of CQY, CUE, and to a lesser extent, HI made on potato plant communities in the field. It deserves to be stated again that in controlled environment studies, HI is known to be influenced profoundly by seasonal temperatures, management, and genetics (Tibbitts et al. 1994; Timlin et al. 2006), which are not addressed in this model. Larger, whole-plant gas exchange measurements are necessary to accurately measure or calculate CQY and CUE. Since there are no commercially available systems to perform these measurements, a variety of systems have been developed and are often tailored to fit a specific crop type (e.g. van Iersel and Bugbee 2000; Miller et al. 1996; Poni et al. 1997; Whiting and Lang 2001). To our knowledge, such work has not taken place yet for field evaluation of whole communities of potatoes.

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