Agrivoltaic Opportunities Assessment and Recommendations for the Sollair Solar Project

Submitted To:

General Land and Power Corp.

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February 2023

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1.0 Introduction

Tannas Conservation Services Ltd. (TCS) was contracted by General Land and Power Corp (PL&PC) to complete an assessment of the potential agricultural uses that are possible within the Sollair Solar Project and to create a reclamation plan to create a native grassland habitat within a portion that can be used to create a native ecosystem that can be used for grazing. I have prepared this report as an independent witness and acknowledge my obligation to provide advice that is fair, objective and non-partisan. A review of related research was completed to inform this report. The following report is focused on understanding the potential strengths and weaknesses of agrivoltaics (i.e., the hybridization of agriculture and solar production) and discusses how to leverage the strengths of this system within Alberta and mitigate the weaknesses.

1.1 Agrivoltaics

Agrivoltaics is a dual use system that simultaneously uses an area of land for both solar (photovoltaic) power generation and agriculture (Coşgun, 2021). Agrivoltaics can be adapted to many forms of agriculture including horticulture (outdoor or indoor greenhouse production), annual crop production, livestock production, and forage production (e.g, hay).

The problem with traditional photovoltaic power production is that it removes land from productive agricultural uses (Klenske, 2022). This results in land conversion and no increase in over all output from land, but in contrast simply a change in the output. Agrivoltaic systems can produce a total output per land area that is greater than either system alone. Land Equivalent Ratios (LER) are often used to measure total output per land area. For agrivoltaic operations, LERs are typically greater than one indicating and efficient use of land area (Amaducci et al., 2018; Campana et al., 2021; Dupraz et al., 2011). Dupraz et al. (2011) predicted an overall increase of 35-73% in land productivity from synergies in agrivoltaic systems.

1.2 Land Use and Agrivoltaics

The ability to produce agricultural products while also producing additional products on the land has a significant appeal from nation wide scale, provincial scale and even to some degree at a municipal scale. If agricultural production is at 100% capacity on a given piece of land and an additional 100% capacity of another land use occurred that would net a 200% economic yield off of a given piece of land. Netting 100% use of a land for two different land uses is unlikely to occur, but if each land use has a reduced output, but the net yield remains above 100% then the area is more productive. Depending on the land uses that are paired together there may be ways for each land use to maintain a productive and profitable state without excluding the other land use. When we approach the topic of agrivoltaics the exact yield that each land use must maintain, at a minimum, to be viable must also be considered. In agriculture, each jurisdiction that works with agrivoltaics has had a different approach and yield expectations for agricultural output varies by jurisdiction. The type of agriculture will determine the output on the land necessary to make it viable. The highest value land uses in Alberta are annual crop production and horticultural production with the lowest economic output per acre are grazing systems. The interaction of photovoltaics (PV) and agriculture can have both positive and negative effects on each other. Agriculture can have a positive impact on energy production. Growing vegetation under PV panels can reduce daytime panel temperature resulting in increased energy production (Abidin et al., 2021; Barron-Gafford et al., 2019).

1.2.1 Effect of Photovoltaic Infrastructure on Plants

The effect of placement of PV infrastructure on agriculture is driven by the effects of PV panels on the environment around them. PV panels have the ability of altering temperatures (Barron-Gafford et al., 2019; Coşgun, 2021), increasing soil moisture (Barron-Gafford et al., 2019), decreasing wind speed (Adeh et al., 2018), and reducing water use of crops (Barron-Gafford et al., 2019; Coşgun, 2021). These changes to microclimatic conditions result in a net benefit to plant growth in reduced drought stress (Barron-Gafford et al., 2019), greater food production (Barron-Gafford et al., 2019) and a positive effect on PV panels in reduced heat stress (Barron-Gafford et al., 2019). The net result of these effects is that crops can have increased productivity in arid environments (Barron-Gafford et al., 2019), although impacts may vary by crop. Shading from PV infrastructure also has varying impacts on crop growth.

PV infrastructure can alter temperatures around them. Some research has noted that PV infrastructure has a minor impact on air temperature (significantly different on only 12 days of season), mostly on calm, sunny days (Marrou, Guilioni, et al., 2013). However other research has noted maximum daily temperatures to be up to 3°C cooler in hot dry periods and up to 2°C warmer when weather was cooler (Hudelson & Lieth, 2021). Soil temperature was reduced in shaded areas by about 2°C in French agrivoltaic systems (Marrou, Guilioni, et al., 2013). Another effect of PV installations is that they can create a heated island effect similar to urban areas that raise the temperature within the installation (Barron-Gafford et al., 2019). The effects on plant growth depends on each specific species with some species having higher productivity due to shade while others are supressed by shade (Barron-Gafford et al., 2019).

Soil moisture is improved under PV infrastructure. Changes in the microclimate around solar panels mean less evaporation from the soil which improves water balance. On a similar note, the presence of PV infrastructure can result in improved water use efficiency. Water use efficiency can be much better for some plants and this yields higher over all productivity and lower water input needs (Barron-Gafford et al., 2019). One study found that pasture grasses under solar panels were 328% more water efficient (Adeh et al., 2018).

Wind speed and direction is altered by PV infrastructure. The overall changes to wind speed depend on surrounding infrastructure. In one study, no significant impacts were noted on wind speed (Marrou, Guilioni, et al., 2013).

Shading from PV panels and infrastructure can have negative impacts on crops. PV infrastructure creates environmental gradients within the farmed area. Even if the impacts on crops are minor, these gradients need to be considered in agronomic plans for the specific crop. PV panels decrease solar radiation available for crop growth (Adeh et al., 2018). The pattern of shading depends on panel arrangement. Arrangements such as checkerboard patterns or north-south orientations can improve the uniformity of light distribution (Cossu et al., 2018; Riaz et al., 2021). Panel density has more impact on radiation available for crop growth than panel tracking technologies (Amaducci et al., 2018). Distance between panel rows significantly affects radiation available for crop growth. For example, one study found that changing row distance from 20m to 5m decreased crop yield by half (Campana et al., 2021). Photosynthetically active radiation was on average reduced by about 30% under tensile style panels with a row distance of 6.3 m and a height of 5 m (Weselek, Bauerle, Hartung, et al., 2021). In the absence of other stressors, decreased light is generally expected to decrease biomass accumulation and yields.

Microclimate modifications from PV panels can vary depending on conditions. Furthermore, impacts of various microclimate modifications can have different impacts on different crops. Impacts can even vary with different varieties and stages of growth for the same crop. For example, shading in early stages of development can have substantial negative impacts, while shading in the heat of summer can reduce stress and improve plant growth.

Table 1-1: Examples of factors that can influence how PV infrastructure is related to crop yields.

Factor	Category	Example
Crop Variety	Agronomic	There are varietal differences in how crops respond to temperatures and stresses under solar panels
Crop Spacing	Agronomic	If light is limiting production than reducing plant populations can reduce competition between plants and improve individual yields
Panel Spacing	PV system	Influences light distribution, amount of shading, efficiency of equipment and operations
Crop type	Agronomic	Some crops are more suited to agrivoltaics, such as C3 crops with shade tolerance
Weather conditions	Environmental	Microclimatic impacts can bring daily conditions closer to the ideal growing conditions for the crop or be further from ideal
Stressors	Environmental	Shading can be beneficial if low moisture is stressing crop growth, but if disease was current stress than shading might have negative impacts on disease spread
Location	Environmental	Daylengths, sun angle, and other location parameters impact total radiation available
Panel height	PV system	More light scattering underneath with taller placement means less shading of the crop
Panel arrangement	PV system	Checkerboard or intermittent arrangements can mean less or more even shading
Panel type	PV system	Some panels block less light as they are more transparent
Crop Arrangement	Agronomic	Shade tolerant crops under panels and sun-loving crops between rows
Panel density	PV system	Portioning between energy and food outputs

1.3 Alberta and Agrivoltaics

1.3.1 Alberta Context

Alberta is located above the 49th parallel and encompasses 64.2 million hectares of land of which 14% is in annual crop production. This represents a small percentage of the province, but a massive area as the province of Alberta has a relatively large land mass. However solar development has been focused on the 20% of the province that is under cultivation with a minor portion on other land uses. This means that only 20% of the area of Alberta is readily available for solar development and all of it is in land currently used for Agricultural production. The class of land as defined by Agriculture Canada's rating system (based on soil type) is class 2 and below (Glen, 2013). The majority of the best quality (class 2) land is located east of Calgary and Edmonton with a sizable portion under threat of urban expansion (Glen, 2013). For this reason, loss of agricultural land for any other reason is not desirable on a provincial scale.

Table 1-2: Estimated breakdown of Alberta by land use related to agriculture

Land Use	Area in Millions of Acres	Area in Millions of Hectares	% of Alberta
Total land in Alberta	158.7	64.2	100%
Land use for agriculture	52	21.0	33%
Land used for grazing	20	8.1	13%
Area under cultivation	32	12.9	20%
Area in Hay and tame pasture	7	2.8	4%
Area in annual crop	23	9.3	14%
Area in summer follow	2	0.8	1%

* Data for this table is from the western producer (Glen, 2013).

The number of farms reporting solar energy production is increasing, with 8.7 % of farms in Alberta reporting solar production in 2021 (St.Pierre & McComb, 2023). A modeling study found that solar power generation potential is greatest over croplands (Adeh et al., 2019). It is therefore important to understand the potential relationships between solar power and agriculture in Alberta.

1.3.2 Alberta Climate and Crops

Mean annual precipitation in the Airdrie area is around 400 to 500 mm per year (Alberta Climate Information System, 2023). During the warmer months of July and August, lower moisture levels can often limit plant growth. In situations where moisture is limiting plant growth, PV infrastructure can help to prevent moisture loss and improve growing conditions for crops.

Plants are often grouped into three categories based on how they photosynthesize: C3, C4 and CAM. C4 plants, tend to be adapted to hot environments and usually have higher light saturation points (Black, 1971; Pearcy & Ehleringer, 1984). Corn is an example of a C4 crop that is grown in Alberta. The majority of crops grown in Alberta are C3 plants, like wheat, oats, barley and canola (Shooshtarian, 2021). Since C3 crops have lower light saturation points they are generally better suited to agrivoltaic applications (Willockx, Uytterhaegen, et al., 2020).

Table 1-3: Production of key crops in Alberta adapted from Shooshtarian, 2021.

Key Crops in Alberta	10-year Average Production in ‘000 tonnes
Spring Wheat	8,593.9
Forages	8,382.2
Canola	5,764.9
Barley	4,563.6
Dry Peas	1,548.1
Durum Wheat	952.1
Sugar Beets	677.6

Oats	636.5
Winter Wheat	213.8
Lentils	196.9
Corn Grain	91.3
Flax	69.8
Fababeans	58.8
Dry Beans	58.5
Rye	44.6
Mustard Seed	39.2
Triticale	22.6

1.4 Project Description

1.4.1 Soils

The proposed project location of 26-27-29-W4M is dominated by the soil map unit ADRK1, and also containing ADRK14, and ADRK10 (Appendix A: Figure 1). These soils are Orthic Black Chernozems of medium texture. The landform is classified as an undulating, high relief with a limiting slope of 4% for all map units. Map units ADRK14 and ADRK10 can have salt affected soils with Solonetzic soils and poorly drained soils. Only one older map of the Canadian Land Inventory was found for the site which covered the Drumheller region. Within this map the Canadian Land Inventory (CLI) classification for this section is comprised of class 1 soils which have no significant limitations for agriculture and class 2D soils which have some limitations for agriculture. The limitation of D rated soils is undesirable soil structure or permeability (Appendix A: Figure 2). While this figure does show class 1 lands, it is in conflict with newer sources that class the best land in Alberta as class 2 (Glen, 2013).

1.4.2 Site Layout

The intended panel arrangement includes north-south panel rows with east-west tracking. The majority of the panels are to be spaced on 6.7 m centres, with a small area on 10 m spacing for testing. The rotation of panels from east to west allows for improved access width for equipment.

With the high value crop land on site choosing agricultural uses that can take advantage of this land quality is desired. The land uses that are typically used in the area are annual crop production which generally is dominated by wheat and canola production which are two high value crops for the region. In addition to this horticultural use has a high value per acre return and would be a recommended high value land use. Hay production is typically seen as a lower return per acre but there is a regional hay export market that brings high returns per acre. Finally grazing generally has the lowest return per acre, but is the easiest to implement. The footprint will be divided into four types of agricultural production with research occurring throughout all 4 areas. These zones will include:

1) Native grassland area (sheep grazing) – largest area on site of 183.4ha (453ac) using a proven land use with solar
2) Annual Crop Production – second largest land use on site using 86 acres on the east side of the site plus an additional 8.5 acres within the solar panels
3) Hay production – 9.9 acres for research into hay crops that perform well within solar panels has been planned

4) Market garden – a smaller high value land use to be implemented on site and can grow to the available market in the Calgary area. This is initially thought to be 1-2 acres that will be taken out of the grazing area and will grow as needed.

1.5 Types of Agrivoltaics

Agrivoltaic systems can be classified primarily on whether they produce crops or livestock and secondly based on if the production system is closed or open (Willockx, Uytterhaegen, et al., 2020). Photovoltaic greenhouses produce crops in a closed system while field crops are produced in an open system (Figure 1-1). There are two main structural options for agrivoltaic systems: lower panels between the crop and higher panels above the crop (Willockx, Uytterhaegen, et al., 2020). The proposed system would be classified as an open system with panels between the farmed area. Both applications and farming types would fit in these parameters.

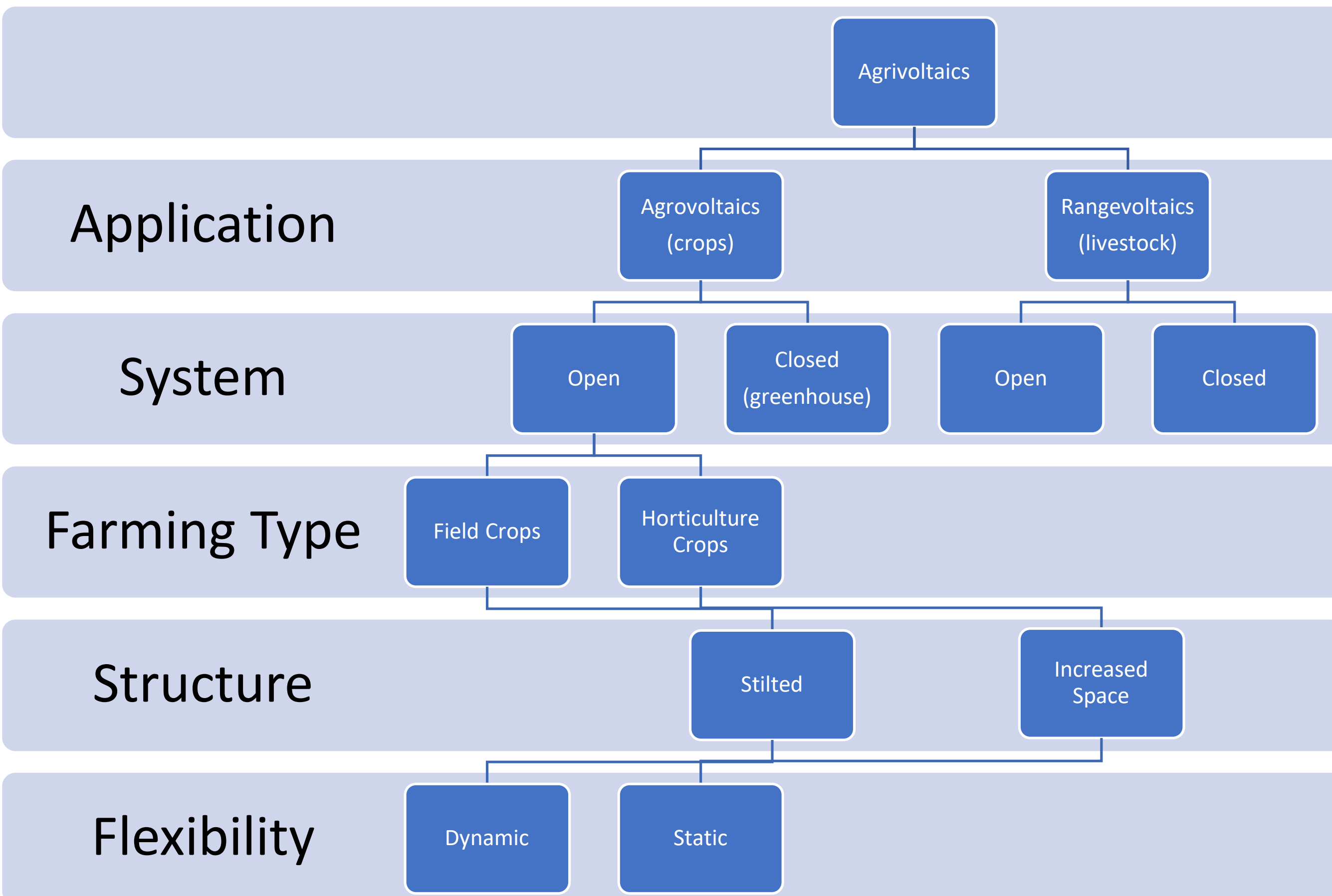

Figure 1-1:Classification of agrivoltaic systems adapted from (Willockx, Uytterhaegen, et al., 2020).

1.5.1 Photovoltaic Greenhouses

Within greenhouses the challenge is that more sunlight is required than in open fields and so solar panels can have a negative effect on production when they cause significant shading (Klenske, 2022). Brite Solar has constructed a 1,000m^2 test greenhouse in Greece covered in nanostructure-coated solar cells able to produce 50 kW of power (Klenske, 2022). Most research on agrivoltaics has been on photovoltaics greenhouses (Toledo & Scognamiglio, 2021).

1.5.2 Open Field Systems

Field crops are produced between or underneath panels. Many arrangements can be configured to meet energy and crop production goals. Less than 30% of research completed on agrivoltaics has evaluated open field systems (Toledo & Scognamiglio, 2021).

Table 1-4: Barriers and solutions to implementation of agrivoltaics in open-field systems. Source (Toledo & Scognamiglio, 2021).

Topic	Design Related Solution	Technology Related Solution
Minimizing shadows on crops (biomass yield)	Optimal design: Distance between the arrays of modules Distance of the modules from the ground	Sun-tracking systems Semi-transparent PV modules (by spacing PV cells) Light-selective PV devices
Maximizing electric energy generation	Optimal planning: Avoiding sharing losses from surrounding elements (structures, buildings, trees, inter-row shading of the PV modules should be minimized) Optimal design: Azimuth facing equator and tilt close to latitude	Highly efficient systems (e.g., sun-tracking systems) Highly efficiency modules or technologies (e.g., bifacial module technology)
Social acceptance (landscape dimension)	Optimal landscape design: Pattern of PV arrays aligned to the parcel Natural fences and low height structures to minimize visual disturbance Use of marginal areas Removable systems Optimal design: Different tilt, azimuth and height to reproduce the orography of the land	New materials for structure
Social acceptance	New business models: Higher economic efficiency per land unit (farmer perspective) Benefits for local economy and employment (tourism, local recreation, etc.)	

1.5.2.1 Panels Above Crop

With this PV structure panels are typically on stilts two to five meters high (Willockx, Uytterhaegen, et al., 2020). Crops can be grown underneath of the panels. The main disadvantages of higher structures are increased visual impacts and greater construction costs for foundations, stilts and reinforcement (Willockx, Uytterhaegen, et al., 2020). SolAgra is an example of a panel system that is designed for equipment to fit underneath. This particular system also has shifting technology to adjust shading based on the environment and crop needs.

1.5.2.2 Panels Between Crop

Lower panels between the crop are more typical for field crops where large equipment is used (Willockx, Uytterhaegen, et al., 2020). Less structural design is required to ensure the PV infrastructure can withstand the wind and elements when it is shorter.

1.5.3 Livestock and Agrivoltaics

For livestock, taller panel arrangement provides shading and keeps the panels above the livestock to prevent damage (Willockx, Uytterhaegen, et al., 2020). For small livestock, such as sheep, panels do not need to be taller for compatibility with grazing. Some grazing systems have used panel lines to act as fences.

Table 1-5: Key strengths and weaknesses of agrivoltaics in Alberta.

Strengths	Weaknesses
Potential to increase overall output per unit of land	Must sacrifice some crop or energy production
Project close to large population with easy access to markets for fresh local agriculture products	Systems not tested in local environment
Panels can be more efficient with crops underneath to help cool panels	Extra expenses and design may be required to accommodate farming activities and adequate growing environment
Shading can improve water efficiency during hot dry conditions	During cooler times of the year shading is likely to have negative impacts on crop growth
Panels can lengthen the growing season	Equipment sizes are large in Alberta limiting panel configurations that work for agriculture

2.0 Literature Review of Potential Crops

The three most important grain crops in Alberta are canola, spring wheat, and barley (St.Pierre & McComb, 2023). These crops have not been tested under agrivoltaics in North America. There are also horticulture crops that can be grown in Alberta, especially considering the potential to market them in the local area. There are many factors that can be taken into consideration when selecting crops within agrivoltic systems (Table 2-1). Information known about each crop in relation to agrivoltaics is discussed in the following sections.

Table 2-1: Factors to consider for crop selection in agrivoltaic systems. Adapted from (Waghmare et al., 2022).

Priority	Parameter	Relevance
1	Sunlight requirements	The crops cultivated in the inter-row spaces and beneath the solar PV module would get less amount of direct sunlight, the possibility of getting diffuse sunlight is higher. Thus shade-tolerant or shade-loving plants are preferred.
2	Soil tillage and land preparation	Crops that need less soil and land preparation, such as perennials, are preferred.
3	Irrigation and water requirements	Excessive moisture could be problematic for PV infrastructure. Panels can increase water use efficiency.
4	Climatic factors	Panels can impact microclimate and therefore crop growth. Each crop has optimal temperature ranges for growth and different stress points.
5	Root depth	Shallow rooted species have been recommended.

6	Height of crop	For low wind resistance and better structural stability of the PV installations, the optimum structure height is selected. Thus, it is required to select the crops suitable for the optimum ground clearance
7	Transpiration potential	In hotter environments, plant transpiration can have important cooling impacts on PV panels.
8	End utility and markets	The food crops, cash crops, horticultural crops, plantation crops, ornamental crops, and medicinal crops can be cultivated in agrivoltaic systems.

2.1 Grain Crops

Grain crops grown in Alberta can be grouped into cool-season cereals, pulses, oilseeds and warm-season crops. Corn is the only warm-season crop that will be discussed here, as other warm-season crops are used mainly as forages in cooler climates. All these grain crops are annuals that can be grown in rotation and require similar equipment which is easily adapted to each specific crop.

Table 2-2: Potential grain crops and predicted response to agrivoltaics in Alberta.

Potential Crop	Response in Agrivoltaic System	Comment	Crop Considered, but eliminated based on…
Wheat	Negative	Usually negative yield impacts, but can see small positive impacts in hot dry conditions	
Barley	Neutral/minor negative	Presumed, not tested	
Rye	Unknown	Minor relevance	
Oats	Negative	Modeled, not tested	
Peas	Neutral/minor negative	Presumed, not tested	
Other pulses	Unknown	Minor relevance	Minor relevance
Canola	Neutral/minor negative	Presumed, not tested	
Sunflower	Unknown	Height concern	Height concern
Flax	Unknown	Minor relevance	
Corn	Negative	Poorly adapted to local climate for grain, used for forage	
Specialty grains	Unknown	E.g., canary seed, camelina, mustard etc.	Minor relevance

2.1.1 Cereals

Most agrivoltaic research on grain crops has been done on wheat, but somewhat similar results might be expected from other cool-season cereal crops. When moisture is not limiting growth, shading caused by PV panels will likely cause yield reductions. This has been demonstrated with other shade sources such as trees and windbreaks (Sparkes et al., 1998; Sudmeyer & Speijers, 2007). In addition to reducing yield, shading can also decrease seed size, impact quality characteristics, and increase moisture content of grain (Li et al., 2012; Sparkes et al., 1998). In a dryland system, moisture can limit crop growth. When shading helps to conserve moisture, yields may be improved (Adeh et al., 2018; Weselek, Bauerle, Hartung, et al., 2021), however other quality and maturity impacts may still occur (Marrou, Guilioni, et al., 2013).

2.1.1.1 Wheat

Previous studies on wheat and winter wheat grown in agrivoltatic systems have been completed in a European environment (Weselek et al., 2019). On 9.5 m row widths, winter wheat yield was reduced by 19% in the first year and increased by 3% on a hotter drier year in a German study (Trommsdorff et al., 2021; Weselek, Bauerle, Hartung, et al., 2021). In France, durum wheat grown under two different PV panel densities matured 2-3 days later than the control (Marrou, Guilioni, et al., 2013). Yield predictions for durum wheat under PV panels might be reduced by 8-19% depending on panel density treatment (Dupraz et al., 2011). This study noted that a 57% reduction in light only resulted in a 19% reduction in yield (Dupraz et al., 2011). In addition to impacting yield, shading can also impact wheat quality (Li et al., 2012).

Variety characteristics such as Leaf Area Index and time to maturity can be used to grow varieties more suitable in an agrivoltaic environment (Willockx, Herteleer, et al., 2020b). An economic evaluation of winter wheat production in Germany using price-performance ratios suggested that agrivoltaic production of winter wheat was non-beneficial (Schindele et al., 2020). Other cereals might be better than wheat for initial inclusion in an agrivoltaic system in Alberta.

2.1.1.2 Barley

Barley is well adapted to Alberta; more barley is grown here than in any other province (St.Pierre & McComb, 2023). Dr. Higgins has reported that barley grows well in their agrivoltaic system in Oregon (Bellini, 2020). However, yield losses are still to be expected (Trommsdorff et al., 2022). A Korean study found that barley under agrivoltaics was 11.5% lower (Nam et al., 2021; Turan et al., 2021). Barley is known for better tolerance of cooler climates and this may be linked to the lower drops in yield under agrivoltaic systems

It is important for malt barley to have even maturity and a very consistent quality. Growing malt barley between panel rows is unadvisable due to concerns with variation in maturity. Targeting feed barley would be more suitable for an agrivoltaic system. Barley is likely to be one of the better annual grain crops for agrivoltaic systems, although it has not been tested here.

2.1.1.3 Oats, Rye, and Triticale

Other cereal crops could be grown, either for grain or forages. Field research was not identified for these crops. However, a modeling study in Sweden considered oats and found that the optimal row spacing for this crop was 9.2m to optimize contributions of both electricity and crop production (Campana et al., 2021). Cereals other than wheat have been generally expected to have neutral impacts (Benghida & Sabrina, 2019; Jain et al., 2021). Oats would be one of the next choices for inclusion in an agrivoltaic system.

2.1.2 Pulses

Foliar diseases are a concern for pulse crops. Microclimate modifications resulting in moisture retention may increase disease risks for pulse crops (Charline, 2020). Breaks in the crop canopy created by PV infrastructure could potentially help offset these concerns. In general, pulses are often sensitive to compaction, so if extra traffic is required for the solar farm this might also be a concern. In the Airdrie area, pulses are not typically grown and as such this is unlikely to be a major consideration at this time. If future breeding of pulses makes them more viable in this region, they could be considered in more detail then. Some pulses are discussed briefly as best management practices for grain crop production include rotating between crop groups for long-term success.

2.1.2.1 Peas

Peas are the main pulse crop grown in Alberta (Table 1-3) and are better adapted to local conditions. Peas are a cool season crop and temperatures over 25 °C during flowering can cause flower abortion (Alberta Pulse Growers, 2023). Reduced temperatures near PV panels could reduce heat stress, however severe shading can also cause flower abortion (Meadley & Milbourn, 1971). Specific research on peas in agrivoltaic systems was not found. However, shading studies have found decreased levels of photosynthesis, decreased leaf area, and reduced biomass (Akhter, Hasanuzzaman, et al., 2009; Akhter, Rahman, et al., 2009). At 75% of full sun, biomass was similar to full sun but results depended on the variety of pea used (Akhter, Rahman, et al., 2009). Based on the characteristics of peas, neutral to negative impacts could be anticipated, but would need to be tested. In hot conditions peas may even benefit from shading.

2.1.2.2 Other Pulse Crops

Other pulse crops include lentils, fababeans, chickpeas, and dry beans. Dry beans are typically grown under irrigation in Alberta. Lentils and chickpeas are typically grown in drier areas of the province. Fababeans were predicted to have neutral to slightly positive outcomes under agrivolatics in Spain (Moreda et al., 2021). However, faba beans have limited demand and require more marketing effort. For these reasons, these pulse crops are not considered to have significant potential for the Airdrie area.

2.1.3 Oilseeds

2.1.3.1 Canola

Canola is in the top three crops produced in Alberta based of both volume and value (Shooshtarian, 2021; St.Pierre & McComb, 2023). Even in norther climates, heat during flowering is a concern. Temperatures over 30°C can cause yield losses with greater temperatures or longer exposure causing greater yield losses (Canola Council of Canada, 2023). Shading on hot days could potentially help to prevent heat stress during flowering.

Although not field tested, negative impacts are expected on canola yield. Based on the need for sunlight, canola has been classified in neutral category for agrivoltaics (Beck et al., 2012; Benghida & Sabrina, 2019; Jain et al., 2021). However other sources suggest that canola still needs significant light and may be negatively impacted by PV panels (Moreda et al., 2021; Trommsdorff et al., 2022). Yield losses of 20% have been estimated when water is not limiting yield (Moreda et al., 2021). In a shading study, yield losses for canola were 17 to 26%, but losses were minimized under drought conditions (Zhang & Flottmann, 2015). Canola is noted for its plasticity, which could imply some adaptability to environmental gradients along PV panels. The drier the region, the more likely the yield drop will be reduced. Canola is a high priority for testing under agrivoltaics in Alberta because of its importance and adaptability.

2.1.3.2 Minor Oilseeds: Sunflowers and Flax

Sunflowers are a tall plant so there may be additional concerns with shading. Sunflowers, however, are native to North America and adapted to the climate in Alberta. Yield differences in sunflowers were not significantly for different row orientations in sunflowers (Robinson et al., 1976). No research on sunflowers or flax grown in agrivoltaic systems was noted. Flax is a less common crop in Alberta (Table 1-3). Sunflowers may be too tall for panels and flax is a minor crop in the Airdrie area.

2.1.4 Grain Corn

Corn is not typically grown at large scale in Alberta due to high moisture and heat requirements (Gabruch & Gietz, 2014). In Japan corn has been grown on small scales under PV panels, but the research location is substantially warmer than the project location (Sekiyama & Nagashima, 2019). At high panel density corn biomass and yield were significantly decreased even in a more favourable growing environment (Sekiyama & Nagashima, 2019). Corn is a C4 plant with high light saturation point which makes it poorly suited to agrivoltaic operations (Sekiyama & Nagashima, 2019). An additional concern with corn is that crop height can easily exceed 2.5 m so panel arrangement may need to be adjusted. Since corn is not well adapted to the area, with additional micro-climate modifications of PV infrastructure, corn for grain production is not recommended.

2.1.5 Height and Spacing Needs for Grain Crops

2.1.5.1 Spacing

Crops like wheat, barley, and canola generally need more light than horticultural crops and so larger spaces between panels are required (Trommsdorff et al., 2022). Up to 1m of row width (0.5m on each side) along mounting structures has been considered unharvestable in some models (Campana et al., 2021). A modeling study in Sweden found that the optimal row spacing for oats was 9.2m to optimize contributions of both electricity and crop production (Campana et al., 2021). Even on wider row widths of 9.5 yield reductions were still significant for grain crops (Moreda et al., 2021; Trommsdorff et al., 2021; Weselek, Bauerle, Hartung, et al., 2021). Going from 20m row spacing to 5m row spacing is expected to decrease yields by 50% (Campana et al., 2021). Although wider row widths have greater grain yields, they also have less energy production per area. In Germany, a lower capacity to area ratio of 600kW/ha is recommended for gain crops than horticulture crops (Trommsdorff et al., 2022). In Japan, agrivoltaics systems are required to maintain 80% of crop yield (Gonocruz et al., 2021). For efficient production of grain crops in Alberta 10m spacing is suggested for initial projects. This spacing allows for optimization of crop yields and easy use of most standard sized farming equipment. The proposed 10m spacing will be a good test for North American field crops.

2.1.5.2 Arrangement Considerations

Simulations with straight line PV arrangement show areas with greatly reduced radiation and areas with next to no reduction in radiation (Willockx, Herteleer, et al., 2020a). Environmental gradients that create differences in crop maturity can problematic in grain crop production. Checkerboard PV arrangements result in more even radiation at ground level (Willockx, Herteleer, et al., 2020a). Although this arrangement improves homogeneity, it would be less compatible with equipment operation for ground mounted PV infrastructure. An Italian study demonstrated that tensile structures had similar land occupation and slightly higher energy production compared to traditional concrete basement structures (Agostini et al., 2021). Various overhead panel arrangements (e.g., SolAgra dynamic shifting) can be arranged to prevent consistent shading of specific areas. Other potential ways to improve light distribution include smaller module rows, and higher panel placement (Jain et al., 2021). Semi-transparent PV systems can also be used to limit shading and improve light distribution (Hassanien & Li, 2017). If there are issues hindering crop production in the proposed system than other arrangements might be considered in future projects.

Harvest and tillage operations for field crops can create considerable dust. Dust from both the agrivoltaic farm and surrounding farms can potentially impact panels. Vertical tilt panels, although more expensive, can decrease the need for cleaning (Riaz et al., 2021). These types of panels also create more even shading (Riaz et al., 2021). It is unknown to what extent dust will be a concern in the proposed agrivoltaic system.

For panel rows, north-south row orientation is preferable for crop growth. Barely yield was 9% greater and oat yield was 4% greater when seeded north-south than when seeded east-west (Austenson & Larter, 1969). This is compatible with current orientation plans.

2.2 Horticulture Crops

Many crops have been studied and have benefits associated with agrivoltaics installations such as lettuce, peppers, tomato, aloe vera, maize and pasture grasses (Coşgun, 2021). Some plants do not need as high of irradiance as cereal crops such as carrots, radish, leek, beet, lettuce, sprouts, cauliflower, spinach, broccoli, pepper, tomato, aloe vera, maize and pasture grasses (Coşgun, 2021). Other leaf vegetables and berries can also benefit from lower light environments (Jain et al., 2021). Although specific impacts vary for each crop, biomass yield is generally correlated with available PAR (Hudelson & Lieth, 2021).

Table 2-3: Potential horticulture crops and predicted response to agrivoltaics in Alberta.

Potential Crop	Response in Agrivoltaic System	Comment	Crop Considered, but eliminated based on…
Potatoes	Neutral	Both increases and decreases have been demonstrated	
Onion	Neutral		
Carrots	Neutral		
Beets	Neutral		
Other root vegetables (Radish, Turnip)	Neutral	suspected	
Lettuce	Neutral	Often recommended for agrivoltaics, but some yield penalties still observed	
Spinach	Negative	More sensitive to shading	
Cruciferous Vegetables	Neutral	Specifics unknown	
Strawberries	Positive/neutral	Decreased production risks	
Raspberries	Unknown	Well-adapted perennial crop	
Saskatoons	Unknown	Well-adapted perennial crop	
Cherries	Unknown	Lower priority for inclusion	Height concerns
Haskup	Unknown	Well-adapted perennial crop	
Blueberries	Unknown		Not suited to soils and local environment
Tomatoes	Negative	High heat requirement	
Peppers	Negative	High heat requirement	
Cucurbits	Negative	High heat requirement	

Grapes and Hops	Negative	Anticipated height concerns
Herbs	Unknown	
Beans	Positive/neutral	
Rhubarb	Unknown	Anticipated to be neutral or positive

2.2.1 Root Vegetables

2.2.1.1 Potatoes

Potatoes are shade tolerant C3 crop that is likely to benefit from reduced drought stress (Willockx, Herteleer, et al., 2020a). Potatoes grown under PV panels had greater leaf area than potatoes grown in a control area indicating the ability of this crop to adapt to shaded conditions stress (Willockx, Herteleer, et al., 2020a). On 9.5m row widths, potato yield was reduced by 20% in one year and increased by 11% on a hotter drier year in a German study (Trommsdorff et al., 2021; Weselek, Bauerle, Hartung, et al., 2021). This suggests that there can be negative and positive effects depending on annual climatic conditions. The hotter and drier the environment the more likely for there to be benefits. Financial benefits of growing potatoes in an agrivoltaic system were found by a German study even considering yield impacts (Schindele et al., 2020).

In 2022, Alberta was the largest producer of potatoes in Canada (Statistics Canada, 2022). Potatoes are often grown under irrigation as marketable tuber yield is reduced when available water falls below 65% (Alberta Agriculture, 2011). Potatoes are grown for seed, commercial processing, and in gardens. For commercial production row spacing would need to be 9.7m to optimize contributions of both electricity and crop production based on a Swedish study (Campana et al., 2021). Spanish predictions for potatoes in agrivoltaic systems range from negative 23% to negative 8% (Moreda et al., 2021). In a market garden scenario, row spacing and water management could be approached differently than in commercial production. Potatoes would be high priority of inclusion in horticulture areas of the proposed system.

2.2.1.2 Onions

Onions are a specialty crop in Alberta, with small amount being recorded in several irrigation districts (Charest, 2019). Shading from PV panels can significantly impact onion growth; however, this impact was reduced with checkerboard panel arrangement (Kadowaki et al., 2012). A Spanish study predicted yield impacts between negative 6% and plus 9% for onion in an agrivoltaic system (Moreda et al., 2021). Onions could be grown in the proposed agrivoltaic system.

Garlic is another bulb vegetable that could be grown in Alberta. Garlic was not investigated in detail at this time.

2.2.1.3 Carrots

Small amounts of carrots are also grown as a specialty crop in several irrigation districts (Charest, 2019). Carrots in agrivoltaic systems are predicted to from 10% less to 5% more than carrots grown in full sun (Moreda et al., 2021). Carrots would fit into a market garden operation in the Airdrie area.

2.2.1.4 Beets and Other Root Vegetables

Sugar beets are grown on a commercial scale in southern Alberta, and garden beets are grown locally. Shading from trees along headlands decreased yield of sugar beets and can impact sugar concentration (Sparkes et al., 1998). Celeriac, a common root vegetable in Europe, was tested in under agrivoltaics. Fresh bulb weight decreased by 19% in one year and increased by 12% in the next year, but overall impacts were not significant (Weselek, Bauerle, Zikeli, et al., 2021). They pointed out that below ground biomass is usually correlated to above ground biomass. Impacts on other root vegetables grown in Albertan gardens, such as radish and turnip, are also expected to be minor in agrivoltaic systems and are common in market gardens.

2.2.2 Leafy and Stem Vegetables

2.2.2.1 Lettuce

Lettuce can tolerate more shading and higher panel density than many other crops (Riaz et al., 2022). Lettuce grown under PV panels adapted to shaded conditions with increased leaf area and flatter leaf orientation to capture more of the available light (Marrou, Wery, et al., 2013). Shading impacts on lettuce development were minimal after the first few weeks of growth, although there were some impacts early on, in particular with some varieties (Marrou, Guilioni, et al., 2013). Another study with lettuce also found minor differences in biomass yields between shaded and full sun areas (Valle et al., 2017). Minor shading can have significantly positive impacts on lettuce growth (Carreño-Ortega et al., 2021). With heavy shading lettuce yields were reduced by 58%, but half the amount of shading had minimal impacts on lettuce yield (Marrou, Wery, et al., 2013). Based on these results, Marrou et al. (2013) suggested that PV design should allow at least 70% photosynthetically active radiation to reach crop level. Lettuce would be suited to an agrivoltaic market garden and could be grown in more shaded areas than some other vegetables.

2.2.2.2 Spinach

Spinach is more sensitive to shading than lettuce. When grown under PV panels spinach produced 26% less biomass, but resulted in 35% greater financial gain when income from PV was considered (Thompson et al., 2020). A Californian study also found that spinach was sensitive to shading and yielded better with higher light levels (Hudelson & Lieth, 2021). In an agrivoltaic system spinach should be grown in areas with more light.

2.2.2.3 Cruciferous Vegetables

Cruciferous vegetables like broccoli, cauliflower, cabbage, kale and brussels sprouts can be grown in Alberta. These crops grow well between 7 and 29 °C (Kaulbars, 2014). A California study found that broccoli required at least 85% of full sun to produce harvestable heads (Hudelson & Lieth, 2021). A different study found that differences between full-sun and agrivoltaics were not significant for broccoli (Chae et al., 2022). Kale yield under PV panels was up to 23% less than control, but there was little biomass difference from 55 to 85% full sun (Hudelson & Lieth, 2021). In hot conditions, shading can be beneficial for kale production (Junior et al., 2019). Agrivoltaic production of cruciferous vegetables is likely possible.

2.2.2.4 Swiss Chard

Swiss chard grown under PV panels yielded from 55-62% less under heavy shade, but under 85% of full sun biomass yields were similar to the control (Hudelson & Lieth, 2021). Swiss chard grows well from 10-29°C (Kaulbars, 2014) and is commonly grown in Alberta gardens. Swiss chard, could be considered for an agrivoltaic market garden operation.

2.2.2.5 Stem Vegetables

Asparagus is a perennial stem vegetable that can produce for over 15 years and grows well between 16 and 29°C (Kaulbars, 2014). Celery grows well in cooler temperatures of 15 to 18 °C, although temperatures below 13°C for long periods can cause bolting (Kaulbars, 2014). These types of vegetables could also be arranged in a market garden with species more adapted to shade and cool temperatures close to the panels, and more sensitive species closer to full sunlight. Rhubarb is another consideration as this is a crop that can grow in cool climates and is found growing in the mountains and up into the arctic circle. As a crop more tolerant of cool conditions it may perform well under panels although no study results were found about rhubarb.

2.2.3 Berries

Dr. Higgins at Oregon State University expects that berries (including strawberries, blueberries, raspberries and lingonberries) would be ideal candidates for agrivoltaic systems, but has not yet tested them (Bellini, 2020). Berry crops often require some protection from birds to prevent substantial production losses. PV infrastructure has been proposed to have advantages for attaching protective netting for high value horticultural crops (Trommsdorff et al., 2022). The crops in this section are higher value perennial crops, and this general category of crops has been recommended over annual crop rotations in Europe for agrivoltaic systems (Schindele et al., 2020). Taller crops, such as orchard have been considered by some experts as a poor fit for agrivoltaics (Bellini, 2020).

2.2.3.1 Strawberries

Modeling work showed promise for the crop and found that the stability of solar income, plus some potential protection, can decrease risk for growing this crop (Cuppari et al., 2021; Trommsdorff et al., 2022). Some greenhouse studies found that strawberries grew better under opaque PV modules than under full-sun or regular panels (Tang et al., 2019, 2020). Strawberries are a promising choice for agrivoltaics in Alberta.

2.2.3.2 Raspberries

Raspberries are commercially produced in Alberta and grow well throughout the province (Alberta Agriculture and Forestry, 2016). Raspberries benefit from wind protection and soil moisture (Alberta Agriculture and Forestry, 2016), which may be improved by PV panel infrastructure. Raspberries grow well and would be a good option for agrivoltaic systems here.

2.2.3.3 Saskatoons

Saskatoon berries are native to Alberta, and as such, are well adapted to the site. The height of these shrubs could be a potential concern for agrivoltaic operations. Saskatoons can often grow to 6 m (Tannas, 2004), but pruning to 2 m is recommended (Alberta Agriculture and Rural Development, 2012). Size may still be a concern that may limit the use of this crop depending on row spacing.

2.2.3.4 Cherries

Some types of cherries can be grown in Alberta. Choke cherry, Nanking cherry, Chinese bush cherry, Mongolian cherry, and western sandcherry are some cherries that could be grown in Alberta (AgriFacts, 1994). Similar to Saskatoons, there may be height concerns with cherries.

2.2.3.5 Haskap

Haskaps are a northern adapted berry, that has been bred for fruit production. Shrubs grown to be about 2m tall and may be mechanically harvested with the same equipment as Saskatoons (Bors, 2010). For mechanical harvest, 5m row spacing in needed, but for manual harvest, a couple meters will do (Bors, 2010).

2.2.4 Grapes and Hops

Grapes and hops are perennial crops that both require types of trellises to support their growth. This means additional infrastructure would be required between rows and could potentially interfere with width available for other activities.

2.2.4.1 Grapes

Some agrivoltaic modeling has been done for grape production in India which suggested minimal impact on grape yield (Malu et al., 2017). Production of grapes will require trellis structure and occupy greater heights than field crops. Recommendations for growing grapes in Alberta include maximum sun exposure (south side of buildings or south facing slopes), lighter soils (promote earlier ripening and higher sugar content), ensuring adequate water (they are sensitive to drought), and mulching (to limit evaporation in the summer and protect plants in the winter) (AgriFacts, 1994). Grape production could be tested in the proposed agrivoltaic system at a small scale, but due to the fact that we are climatically on the edge of the growing region for even the hardy grape varieties it is unlikely that grapes will be viable.

2.2.4.2 Hops

Hops are a very minor crop in Alberta (Elford, 2016). Hops require trellis structures 5.5 to 6.5 m tall and about 2-4m between rows (Elford, 2016). A crop this tall could shade PV panels in the proposed system, but has been suggested in various literature as a good fit for agrivoltaics (Jain et al., 2021; Schindele et al., 2020; Trommsdorff et al., 2022). However, this would be for tall the style of PV structures, and not suitable for the current project.

2.2.5 Garden Vegetables with Greater Heat Requirements

Tomatoes and peppers have shown promise in other regions, but likely need hotter conditions to work well in agrivoltaic systems (Bellini, 2020). Base temperatures for growth of solanaceous crops like tomatoes peppers and eggplants are 10-15 °C and 15°C for cucumbers (Kaulbars, 2014). Melons and squashes also have a base temperature of over 10°C for growth (Kaulbars, 2014). For production of these crops to occur in agrivoltaics in Alberta, they should be prioritized for areas with less shading and may require some type of cold-frame structure to retain heat around plants.

2.2.5.1 Tomatoes

Cherry tomatoes were shown to have higher CO_2 uptake, water use efficiency and significantly higher fruit production under PV installations (Barron-Gafford et al., 2019). This study was conducted in much warmer climates than we have in Alberta, and as such the effect for these species may not hold, but it does show the effects that are possible. Tomato biomass was similar to control when PV panels blocked up to 55% of full sun, indicating reasonable shade tolerance (Hudelson & Lieth, 2021). In Oregon, tomatoes grown under panels yielded 51% less and tomatoes between panels yielded 39% less (Al-Agele et al., 2021). Yield predictions for tomatoes under agrivoltaics in Spain ranged from a 5% decrease to a 10% increase (Moreda et al., 2021). However, both these studies are from warmer climates, so shade might cause greater yield reductions sooner in Alberta.

2.2.5.2 Peppers

Chiltepin peppers saw increased productivity and increased CO_2 update with no impact to water use. Jalapenos had reduced CO_2 uptake and slightly reduced fruit production and higher water use efficiency (Barron-Gafford et al., 2019a). This suggests that some peppers that are tolerant of shade and lower temperatures will clearly benefit from PV panels while others that are adapted to direct sunlight may not see a benefit. A study in California noted that floral abortion occurred in areas that received less than 85% of full which reduced pepper yield in these areas (Hudelson & Lieth, 2021).

2.2.5.3 Cucurbits (squashes, melons, and cucumbers)

Various squashes and melons (e.g. zucchini, pumpkin, spaghetti squash, acorn squash, cantalope) can be grown in Alberta, but require extra effort to extend the growing season and create a warmer micro environment (Kaulbars, 2014). Melons grown under agrivoltaics have been predicted to yield 2-17% less (Moreda et al., 2021). Shading of cucumbers in agrivoltaics in France resulted in slower rates of leaf apparition (Marrou, Guilioni, et al., 2013). Various squashes and melons could be tested for the market garden, using practices to extend the growing season.

2.2.6 Other Garden Vegetables

2.2.6.1 Herbs

Basil grown under PV produced 15% less biomass, but resulted in 2.5% greater financial gain when income from PV was considered (Thompson et al., 2020). Dill and mint are examples of herbs that are commercially grown under irrigation in Alberta (Charest, 2019). Various herbs would be worth trying under agrivoltaics in Alberta for market garden purposes.

2.2.6.2 Beans

Beans grow best at temperatures between 16 and 24°C (Kaulbars, 2014). In Japan, the shading rate for beans is between cereal crops and root vegetables for agrivoltaic farms with a shading rate of about 36% (Tajima & Iida, 2021). Beans have been suggested as relatively shade tolerant and benign for agrivoltaics (Benghida & Sabrina, 2019; Jain et al., 2021; Waghmare et al., 2022). Beans are a popular vegetable for local market gardens.

2.2.6.3 Peas

Peas grow well in Alberta. In addition to grown for grain, peas could be grown in a market garden. Impacts on fresh peas might be similar to those for grain peas (2.1.2.1). Peas would be another suitable choice for an agrivoltaic market garden.

2.2.7 Height and Spacing Needs for Horticulture Crops

The proposed spacing of 6.7m would be suitable for most horticultural crops. Within this space, rows can be arranged so that crops more tolerant of shade are grown closer to the PV panels. Simulations with straight line PV arrangement show areas with greatly reduced radiation and areas with next to no reduction in radiation (Willockx, Herteleer, et al., 2020a). Environmental gradients can be planned on so that impacts on the various crops are minimized. Growing various crops in a market garden business will help to reduce the risk of certain crops or varieties failing in the agrivoltaic system. Production of horticulture crops in a market garden style will require less specialized equipment, that might otherwise require different spacing. Many horticulture crops need irrigation to be successfully and consistently grown. Water use efficiency in agrivoltaic systems is improved by shading effects (Elamri et al., 2018). Bifacial modules have been suggested for horticulture PV systems to increase cost effectiveness and electricity production (Jain et al., 2021). The proposed arrangement and spacing should allow most horticulture crops adapted to Alberta to be grown.

Other spacings and arrangements have been investigated if other specific needs are identified. Checkerboard PV arrangements result in more even radiation at ground level (Willockx, Herteleer, et al., 2020a). A checkerboard arrangement can be set up on greenhouses without creating a maze for agricultural operations. If greenhouses under PV panels are considered, there would be additional options. Especially in Alberta, many horticulture crops are grown in controlled greenhouse environments. Shading in greenhouses is used to help manage temperatures and conditions in greenhouse environments. Use of PV panels on greenhouses is justified by most studies on the topic, but the percentage of shading required for different crops is not known. In some field operations cold frames and low tunnels are used to extend the season for field production. These tunnels may fit between the panels effectively allowing for integration of tunnel growing with panels. Some of the horticulture crops discussed are typically started indoors and transplanted to extend the season enough that they can grow in Alberta.

2.3 Forage Crops

Forages are the second largest crop in Alberta by volume (Table 1-2). With over 40% of Canada's beef herd in Alberta (St.Pierre & McComb, 2023), it is understandable why forages are needed here. Forages make up most of a cow's diet, but they are bulky and inefficient to transport. Annual forages include cereal crops (such as those listed in section 2.1), peas, and C4 grasses like corn and millet. Varieties of these crops are adapted to forage production and have some advantages in agrivoltaic systems. Homogeneity is less important in forage production. Impacts on maturity, grain quality, and other shade affects are less likely to be noticed in forages, compared to grain crops where they are a concern. Mixtures of species can also be used to fill in resource gradients between panels, and in many cases, mixtures have improved forage quality.

Perennial forage crops have similar benefits, plus additional advantages. Examples perennial forages in Alberta include bromegrasses, timothy, orchard grass, reed canary grass, alfalfa, clovers, and sainfoin. This type of crop provided year-round ground cover. Less erosion (less dust on panels), longer period of energy capture, and better nutrient retention are some of the key advantages of perennial cover. NW of Airdrie is a major hub for hay production with Japanese export hay as well as hay production that is shipped domestically. Airdrie is in proximity of the region where a significant amount of hay is produced making this a potentially viable crop type.

A study in Oregon found that pasture grasses under solar panels were 328% more water efficient (Adeh et al., 2018) which resulted in 90% greater biomass production. This study area was in a water limited environment. While a study in Germany over two years found a yield reduction of 5-8% for grass-clover mixture, but this yield reduction was less than other crops in the study (Weselek, Bauerle, Hartung, et al., 2021). Analysis of alfalfa in agrivoltaics found that the combination was 2.62$/acre more profitable and reduced weather risks (Cuppari et al., 2021).

In this part of Alberta, water is more likely than light to limit forage growth so it would be reasonable to expect similar or improved forage growth in an agrivoltaic system. Forages have been reported to perform well in agrivoltaics systems in Oregon (Bellini, 2020), which appears to be one of the closest research centres for agrivoltaics.

2.3.1 Height and Spacing Needs

Since forages are less sensitive to shading than most grain crops, less space would be required between rows to minimize yield impacts. The main consideration for panel arrangement in forage based agrivoltaics is equipment requirements. Equipment for haying and managing forages is available at narrower widths than for grain crops, so areas where forage is grown can likely by combined with tighter panel arrangements.

The German study had bifacial PV panels with a row distance of 6.3m (a row width of 3.4m) and a clearance height of 5m (Weselek, Bauerle, Hartung, et al., 2021). The Oregon study had panels about 1m high and 6m apart (Adeh et al., 2018).

2.4 Grazing Potential

Any of the forage crops mentioned in the previous section, as well as native forage blends, would be suitable for grazing. Although the beef industry is well established in Alberta, cattle are large and could easily cause damage to PV infrastructure. Grazing with smaller animals, like sheep or goats, is a better fit for agrivoltaic systems. The sheep and goat industry in Alberta is small, accounting for only about 1% of Alberta's agriculture industry (St.Pierre & McComb, 2023).

Agrivoltaic systems with sheep grazing have been evaluated in Oregon and show promise. Total and daily weight gains for sheep were similar in agrivoltaic systems and open pastures (Andrew et al., 2021). This particular study found at 38% decrease in forage production under PV panels (Andrew et al., 2021), however other studies have found increased forage production with PV panels up to 90% (Adeh et al., 2018). Andrew et al. (2021) noted that increased forage quality offset the decrease in forage production and suggested that overall land productivity was increased by combining sheep grazing with PV. PV panels provide an effective shade source for sheep (Maia et al., 2020). During warmer, drier periods sheep in the agrivoltaic system consumed less water than sheep in the open (Andrew et al., 2021). Land use efficiency of forage production and lamb weight gains were 1.68 to 1.81 and 1.97 to 2.04 respectively for tested agrivoltaic systems (Andrew et al., 2021).

Forage and grazing lands also provide habitat and forage sources (pollen and nectar) for pollinators. Solar panels alter the timing of flowering so that floral resources are available later into the summer (Graham et al., 2021). This could benefit native pollinators or be used as a forage source for beekeeping.

2.4.1 Height and Spacing Needs

Panels will likely provide sufficient summer shelter, but water infrastructure will be required for grazing. The site should be reviewed before beginning grazing to ensure animal safety and well-being.

An advantage of grazing is that animals can graze right up to panel bases, whereas anything with equipment will need a few inches on either side to prevent damage to equipment and PV infrastructure. In the Oregon studies, the lowest edge on the panels was 1.1m high and the panels were spaced 6m apart (Adeh et al., 2018; Andrew et al., 2021). Sheep are a good choice because they are easy to handle with minimal handling facilities.

3.0 Literature Review of Potential Equipment

3.1 Equipment for 6.7m spacing

3.1.1 Grain Crops

3.1.1.1 Seed Bed Preparation (Tillage)

With a width of 6.7 m, there are two main styles of equipment for tillage. The first is an offset disk such as the ones manufactured by Kello Bilt which are offered in various styles and sizes but for example the model 225 is available in widths from 10’2” (3.1m) to 16’9” (5.1m). An offset disk would be used for primary tillage and debris management.

The second style would be a rotary tiller such as those manufactured by Sovema. These are also available in various working widths. An example would be the model RTX-2 which is available from 1.8m up to 3m. These would be for secondary tillage and final seed bed preparation.

3.1.1.2 Seeding

A panel width of 6.7 m will limit the selection of seeding equipment to box type drills, there are no current air seeding systems that are narrow enough to fit between the panel rows. Three options have been identified:

- John Deere 1520 double disc drill 15’ (4.5m)
- John Deere 1590 no till drill 10’ (3.0m) and 15’ (4.5m)
- Great Plains min till drill 12’ (3.7m), 15’ (4.5m)

3.1.1.3 Crop Management

Crop management would include herbicide and fungicide application. For this, options would include UTV mounted sprayers such as those offered by Demco which has a working width of up to 18’ (5.5m). There would also be sprayers that attach to the 3-point hitch of a tractor such as those made by Fimco Industries.

3.1.1.4 Harvesting

For Harvesting, CaseIH has one header option 17’ (5.2m) that would work between the panels. This would need to be used on a class 5 or 6 combine. This would be used for any crops that could be straight cut. For any crops that would need to be windrowed before harvesting, MacDon has a draper header model D65 available in 15’ (4.6m) that would be an option when paired with a pickup header on a combine. This may be at the very bottom end of combine capacity and might hinder grain cleaning and separation and the physical machine width of the combine may also be a limiting factor. Importing a combine from Europe even though they are typically smaller, is not regarded as an option. This is due to unknown emission differences and parts availability.

When harvesting it is also important to consider tank volume and crop yields as combines will not have enough space to turn around. Backing up between rows and driving over crop are not desirable so the tank needs enough capacity to reach the ends or breaks in the panel rows where it can unload.

3.1.2 Forage Crops and Grazing

3.1.2.1 Seed Bed Preparation (Tillage)

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3.1.2.3 Hay Cutting

Due to the width of 6.7m, equipment for hay cutting will be limited to self propelled options. All major equipment manufactures with a line of hay equipment will have a self-propelled option. The example used for this is the New Holland speed rower. The speed rower has two available cutting heads that are under 6 m. The first is the conventional sickle-style haybine which is 14’3” (4.3m) and the Durabine 416 disc cutter 16’3” (4.9m).

3.1.2.4 Hay Raking

Hay rakes are used to assist with the drying process. There are two styles offered by various manufacturers that would be applicable for a 6m working width. Both bar rakes and rotary rakes would be options.

3.1.2.5 Hay Baling

There are two options for baling that are applicable to a 6.7m width; small square bales and round bales. Round bales are produced in various sizes and balers are available from a number of manufacturers. Any round baler will be narrow enough for operation between panels.

Small square balers are available in two styles, offset and inline. For a 6.7m width because an offset baler puts the baler off to the side of the tractor, it would not be recommended. An inline small square baler puts the baler directly behind the tractor. There is only one current option for an inline small, that is the Massey Ferguson 1800 baler. With small square bales, bale handling also needs to be a consideration. For this, a bale accumulator is used. Norden MFG is a company that makes an accumulator, which is pulled behind the baler and groups them for easy pickup. They also make a bale grabber which is mounted on a skid steer or tractor loader and can pick up the groups of bales and move and stack them.

3.1.3 Horticulture Crops

Berry crops are the main horticulture crops for which larger equipment might be used. Horticulture crops generally require less or smaller equipment than grain crops. Previously mentioned tillage equipment as well as small specialty equipment can be used for general horticulture operations.

3.1.3.1 Harvesting

One mode of berry harvester for use with Saskatoon was identified. This is produced by Jagoda, the Oskar A01 has a working width of 4.6m. As this is a pull type machine, needing a tractor, information was not available to know the total working width. With a tractor this may be too wide to use between the rows unless the rows are planted offset from centre.

3.2 Equipment for 10m spacing

The 10m spacing is a common spacing recommended for maximizing crop yield, but also because it is the minimum width needed to accommodate most standard sized farm equipment for annual crop production.

3.2.1 Grain Crops

3.2.1.1 Seed Bed Preparation (Tillage)

With a width of 10m, there are more options of equipment for tillage. An offset disk such as the ones manufactured by Kello Bilt which are offered in various styles and sizes but for example the model 225 is available in widths from 10'2" (3.1m) to 16'9" (5.1m). An offset disk would be used for primary tillage and debris management.

Secondary tillage would have more options. A rotary tiller such as those manufactured by Sovema. These are also available in various working widths. An example would be the model RTX-2 which is available from 1.8m up to 3m. These would be for secondary tillage and final seed bed preparation. Other options such as a field cultivator from CaseIH offer options that as small enough to fit between the panels.

3.2.1.2 Seeding

A panel width of 10 m still has limitations of seeding equipment, to box type drills, and one manufacturer of air drill.

Box drills are still the same as previous. Three options have been identified:

- John Deere 1520 double disc drill 15' (4.5m)
- John Deere 1590 no till drill 10' (3.0m) and 15'(4.5m)
- Great Plains min till drill 12' (3.7m), 15'(4.5m), 24' (7.3m) and 30' (9.1m)

Air drill

- Great Plains NTA 2007 (6.1m) and NTA 3007 (9.1m)

3.2.1.3 Crop Management

Crop management would include herbicide and fungicide application. Two manufacturers were found that have working widths that are under 10m.

- Top Air 300 gallon sprayer 30’ (9.1m)
- Demco RM 21’ (6.4m) and 30’ (9.1m)

3.2.1.4 Harvesting

For harvesting, an example is CaseIH. Their product line has two options for headers, flex and rigid. It is important to make this distinction as pulse crops will require a flex type header.

- Rigid Header 17’ (5.2m), 20’ (6.1m), 24’ (7.3m), 30’ (9.1m)
- Flex header 20’ (6.1m), 25’ (7.6m) 30’ (9.1m)

The biggest limitation is row length, planning it so the combine does not have to empty the grain tank mid row would be required.

3.2.2 Forage Crops and Grazing

3.2.2.1 Seed Bed Preparation (Tillage)

With a width of 10m, there are more options of equipment for tillage. An offset disk such as the ones manufactured by Kello Bilt which are offered in various styles and sizes but for example the model 225 is available in widths from 10’2” (3.1m) to 16’9” (5.1m). An offset disk would be used for primary tillage and debris management.

Secondary tillage would have more options. A rotary tiller such as those manufactured by Sovema. These are also available in various working widths. An example would be the model RTX-2 which is available from 1.8m up to 3m. These would be for secondary tillage and final seed bed preparation. Other options such as a field cultivator from CaseIH offer options that as small enough to fit between the panels.

3.2.2.2 Seeding

A panel width of 10 m still has limitations of seeding equipment, to box type drills, and one manufacturer of air drill.

Box drills are still the same as previous. Three options have been identified:

- John Deere 1520 double disc drill 15’ (4.5m)
- John Deere 1590 no till drill 10’ (3.0m) and 15’(4.5m)
- Great Plains min till drill 12’ (3.7m), 15’(4.5m), 24’ (7.3m) and 30’ (9.1m)

Air drills

- Great Plains NTA 2007 (6.1m) and NTA 3007 (9.1m)

3.2.2.3 Hay Cutting

Due to the width of 10m, equipment for hay cutting will be limited to self propelled options. All major equipment manufactures with a line of hay equipment will have a self-propelled option. The example used for this is the New Holland speed rower. The speed rower has two available cutting heads that are under 6 m. The first is the conventional sickle-style haybine which is 14’3” (4.3m) and the Durabine 416 disc cutter 16’3” (4.9m).

3.2.2.4 Hay Raking

Hay rakes are used to assist with the drying process. There are two styles offered by various manufacturers that would be applicable for a 6m working width. Both bar rakes and rotary rakes would be options.

3.2.2.5 Hay Baling

There are two options for baling that are applicable to a 10m width. Small square bales and round bales.

Round bales are produced in various sizes and balers are available from a number of manufacturers. Any round baler will be able to be used between the panels.

Small square balers are available in two styles, offset and inline. For a 10m width because an offset baler puts the baler off to the side of the tractor, it would not be recommended. The larger width of 10m allows room for this but not easily managed as equipment will need to pass down each width between panels twice. Using the same equipment as the 6.7m spacing is recommended. An inline small square baler puts the baler directly behind the tractor. There is only one current option for an inline small, that is the Massey Ferguson 1800 baler. With small square bales, bale handling also needs to be a consideration. For this, a bale accumulator is used. Norden MFG is a company that makes an accumulator, which is pulled behind the baler and groups them for easy pickup. They also make a bale grabber which is mounted on a skid steer or tractor loader and can pick up the groups of bales and move and stack them.

3.2.3 Horticulture Crops

Berry crops are the main horticulture crops for which larger equipment might be used.

3.2.3.1 Harvesting

One mode of berry harvester for use with Saskatoon was identified. This is produced by Jagoda, the Oskar A01 has a working width of 4.6m.

3.3 Equipment and operational considerations

Typical North American equipment for grain crops is large and a typical PV framework would disrupt operations and require specialized equipment. For example, combines harvest large quantities of grain and need to reach trucks before tanks fill (there will not be enough space to turn combines around even on 10m spacing). This requires augers and trucks that need extra space for maneuverability. Adapting PV structures to accommodate the larger equipment required to manage grain crops can increase mounting costs (Jain et al., 2021). Typical agrivoltaic systems have PV panels mounted 2-5m above ground with a suspension system to facilitate farming operations underneath (Campana et al., 2021). In some situations, lower panel elevation may interfere less with large equipment operation (Jain et al., 2021). Plot equipment designed for research would easier to navigate around PV panel infrastructure, but this type of equipment would be more expensive and less efficient for large grain volumes.

Equipment will not reach right to panel bases as a buffer will be required for equipment operation. The buffer would need to be managed to prevent unwanted growth and weeds.

3.3.1 Site Needs

The different agricultural uses will have some unique requirements that will be implemented to ensure that solar production and agricultural production can be completed in the same footprint. Areas with hay production and annual cropping will have buried lines to allow equipment passage. Areas with sheep grazing will have protection of lines so that sheep will not chew them. Row spacings are being designed to allow equipment passage through the site. Water sources can be temporary and simple or more permanent, but will need to be planned so that sheep have water access while grazing.

Table 3-1: Links to equipment options referred to in section 3.

New Holland	https://agriculture.newholland.com/en-us/nar/products/haytools-spreaders/speedrower-plus-sp-windrowers
New Holland	https://agriculture.newholland.com/en-us/nar/products/haytools-spreaders/windrower-headers
John Deere	https://www.deere.ca/en/seeding-equipment/
Great Plains	https://www.greatplainsag.com/en/implements/united-states/drills
Berry harvester	https://www.agriexpo.online/prod/jagoda-jps-agromachines/product-184797-134466.html
CaseIH	www.caseih.com
Sprayers	https://www.demco-products.com/agriculture/application-equipment/sprayers/three-point-sprayers/rm-series-150-200-gallon
Sprayers	https://www.topairequip.com/3pt-sprayers/300-gallon/
Tillage	https://kello-bilt.com/products/offset-discs/84-model-225-offset
Haying	https://www.nordenmfg.com/product/accumulator-systems/
Tillage	http://sovemacanada.ca/catalogue/shop/soil-preparation/rotary-tillers/fixed/rtx-2/
Grains	https://www.macdon.com/products/d-series-draper/d65-series
Haying	https://www.masseyferguson.com/content/masseyfergusonglobal/en_ca/products/hay-and-forage/square-balers/mf-1800.html
Fimco Sprayers	https://www.fimcoindustries.com/category/sprayers/3-point-sprayers/

4.0 Recommendations

No previous agrivoltaics research was identified in western Canada. Research on agrivoltaics in Alberta is recommended to verify its potential fit with local climates and cropping systems (Jamil & Pearce, 2023). Exact outcomes for an agrivoltaic system in Airdrie, Alberta are unknown, however there is potential for productive systems. Agronomic planning can help to minimize losses within the constraints of the system.

4.1 Annual Crop Production

There is a strong case to be made for integration of annual crop production into agrivoltaic systems. However, 10 m spacing for panels is required for efficient equipment operation and better yields. This size requires a solar farm to be planned for this scale from day one as a much larger land base is required to produce the same electricity yields. It would double the footprint of most solar farms at a minimum. It is recommended for research purposes that a portion of the solar farm be devoted to this type of production so that it can be effectively researched and piloted in Alberta for future implementation and wide scale.

4.2 Market Garden

Another option horticulture production on site. This is the highest value land use per hectare, but the overall scale of demand is lower. With the site location there is however a high value horticultural land use that can be employed on site. Market gardens can be managed to supply produce to the Airdrie and Calgary markets. There is a wide variety of horticultural crops that can be grown in field in the location of the site. To extend the season low tunnels may be used in the spring and fall. This will allow production of crops typically not seen outdoors such as cucumbers which have been grown in field in the Red Deer area. A market garden growing various horticulture crops would be a higher-value option.

4.3 Forages and Grazing

Forage production such as grazing for sheep is the easiest implementation for production but is a lower value agricultural use. For this reason, it should be implemented for its benefits of providing permanent vegetation cover and weed control, but where other more economical crops are available, they should be prioritized. The use of a native grassland instead of a using tame pasture allows for increased biodiversity and an overall environmental benefit to the site. It also could lead to the site being used for honey production in the future. The only requirement for sheep is all wires must be protected from the sheep chewing on them.

The use of the site for hay production shows a modest increase in economic value over grazing alone and as such should be considered as a worth while development for production on site. The spacing of 6.7m allows for effective use of the site by haying equipment that is of a standard commercial size and also allows for weed control and elimination of erosion on site. The only requirement for hay production is buried cables so that equipment can pass between each row of panels.

Certification Page

I hereby certify that:

The requested surveys and reporting were completed by qualified professionals (Steven Tannas) who considered all factors and influences that are within the scope of this assessment.

No person at Tannas Conservation Services Ltd., or associated sub-consultant working on this project have any contemplated interest in the property being assessed.

This report has been completed in conformity with the standards and ethics of the Alberta Institute of Agrologists and the Alberta Society of Professional Biologists.

Respectfully submitted:

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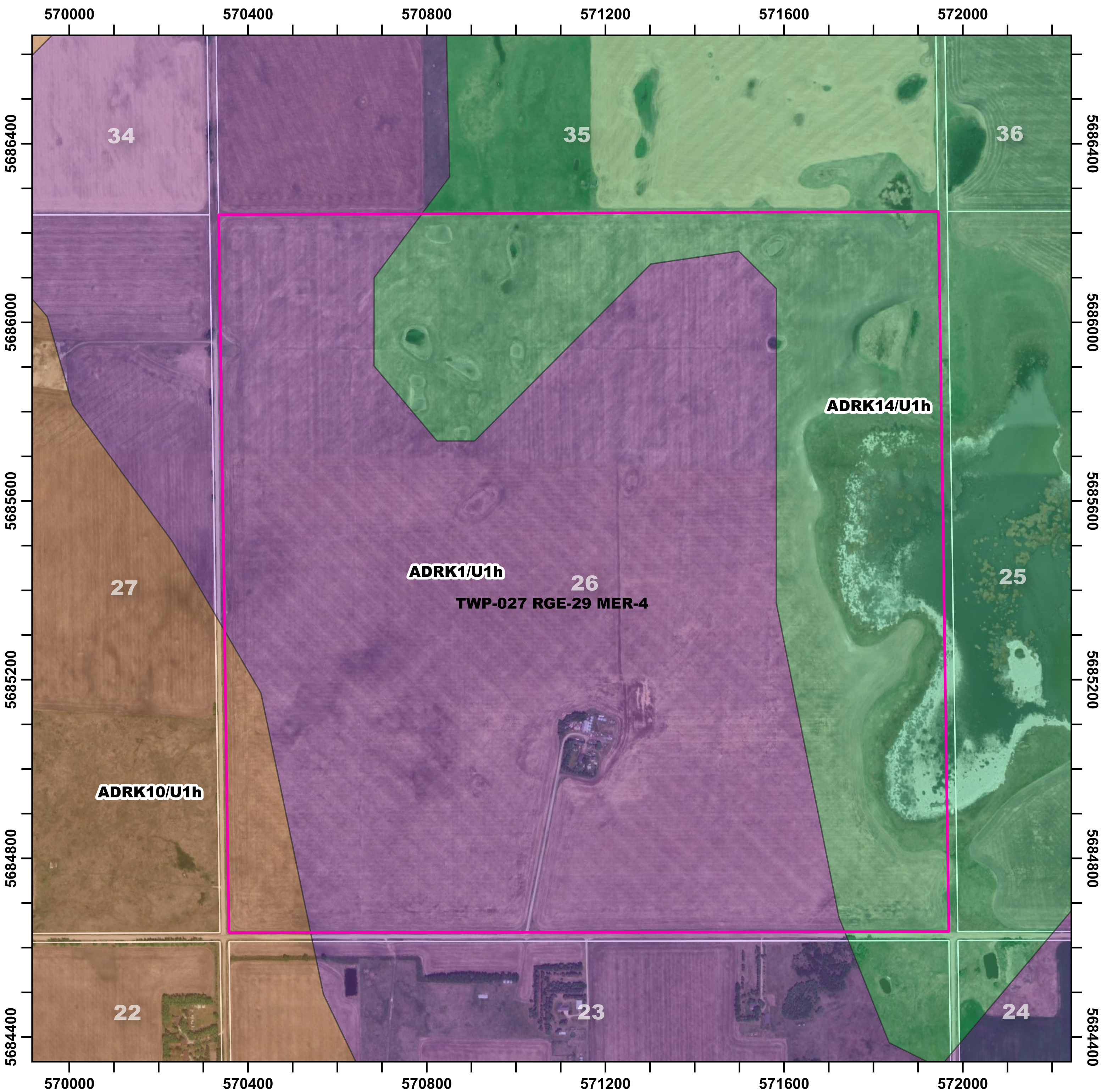
Appendix A

Soil Maps



Legend

AGRASID Soils

- ADRK1/U1h
- ADRK10/U1h
- ADRK14/U1h

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Figure 1

Sollair Solar Project
26-27-29-W4M
AGRISID Soils Layer

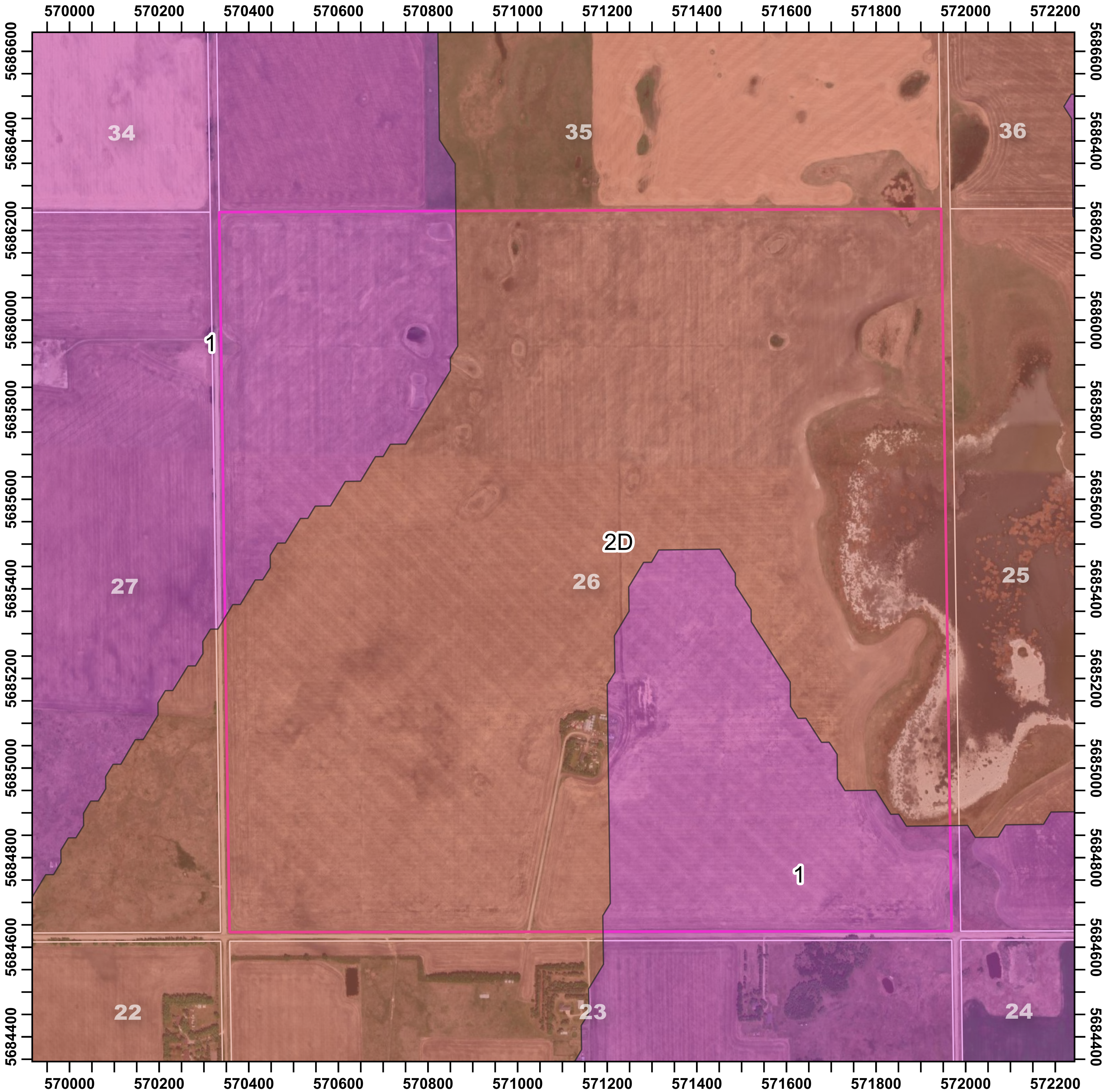
N

Scale: 1:12,000

0 100 200 300 400 500

Valtus Imagery: Sep 1 to Oct 9, 2017

Coordinate System: NAD83 / Alberta 3TM ref merid 114 W



Legend

CLI Class

1 - Soils in this class have no significant limitations in use for crops

2D - Soils in this class have moderate limitations that restrict the range of crops or require moderate conservation practices. Also contains undesirable soils structure and/or low permeability

Tannas Conservation Services Ltd

Figure 2

Sollair Solar Project
26-27-29-W4M
Canadian Land Inventory
Soil Capability For Agriculture

N

Scale: 1:12,000

0 100 200 300 400 500

Valtus Imagery: Sep 1 to Oct 9, 2017

Coordinate System: NAD83 / Alberta 3TM ref merid 114 W