UNIVERSITY OF DELAWARE
COOPERATIVE
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Mapping with Drones: Optimal Times for Delaware

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Shade and Sensor Readings

When creating maps of field crops, one goal is to estimate plant health or responses to management. To achieve consistent imagery, drone flights must account for lighting conditions. While discussions often focus on avoiding variable cloud cover by flying on clear or overcast days (Figure 1), the sun's angle also plays a critical role.

Figure 1: Cumulus clouds cast variable shadows across field plots in Delaware. These shadows affect the light reflected from plants back to cameras or sensors, causing differences across plots not related to crop growth (photo: Jarrod Miller).

Low **solar angles** can cast long shadows across the field, including from the crops themselves, altering the information captured by drone sensors (Figure 2). Cameras and sensors on drones are typically passive and rely on sunlight as their primary light source. When mapping field crops to make management decisions, such as nitrogen applications, recommendations are based on how a plant reflects sunlight. However, when shading occurs, the sensor readings can be distorted. As a result, the accuracy of these recommendations can be compromised in shaded areas, potentially leading to incorrect guidance.

The effect of shading changes with sun angles throughout the day. Sun angles are lowest near the horizon at sunrise and sunset and highest at **solar noon**—the point when the sun reaches its peak position in the sky for a given location (Figure 2). When the sun is lower on the horizon, it casts longer and more pronounced shadows across the field, which can affect sensor readings. This effect varies by latitude, as the sun is only directly overhead at the equator. In Delaware, located in the northern hemisphere, the sun remains in the southern sky throughout the year. Solar angles are higher in the summer and lower in the winter, meaning shadows are more pronounced during the winter months.

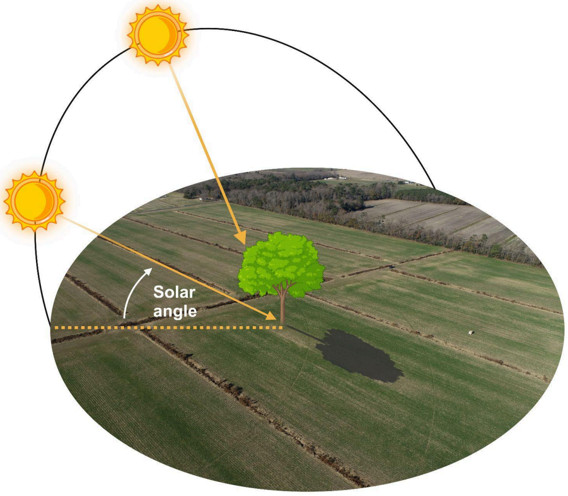

*Figure 2: The **solar angle** is the sun's position relative to the horizon, while the highest position is solar noon. Shadows will be longer at lower sun positions (lower angles). Only at the equator can the sun be directly overhead (90° solar angle) at solar noon (photo: Jarrod Miller/Biorender).*

Crop Growth Stages and Shading

Besides solar angles, crop characteristics such as canopy density, row spacing, and plant height influence reflectance measurements. Canopy density generally has a greater impact on light reflectance than solar angles (Lord et al., 1988). A dense canopy with a high leaf area index (LAI) reduces the influence of soil reflectance, improving the accuracy of plant health assessments (Figure 3). For example, high-LAI crops such as corn and sunflower are less affected by solar angles than wheat and barley, which have lower canopy densities (Lord et al., 1988).

Figure 3: a) More shadows in the foreground occur as the corn closes the canopy, while the background corn is behind in growth stages, and b) a closed soybean canopy completely shades the ground, capturing a majority of sunlight at the top of the plant (photo: Jarrod Miller).

These effects also depend on the crop growth stage (Figure 3). Early-stage corn, with its lower canopy density and LAI, is more sensitive to solar angle effects (Ranson et al., 1985). At lower LAI, shadows reduce contrast between soil and plants, making comparisons more challenging (Ranson et al., 1985). Row spacing and orientation (Figure 4) also play a role—wider rows allow more light penetration, which can increase the contrast between sunlit and shaded areas (Lord et al., 1988).

However, the influence of solar angle varies by wavelength. Red (R) reflectance is less affected in high-LAI crops like corn, but wider row spacing and lower plant density make solar angle a more significant factor (Ranson et al., 1985; Lord et al., 1988). Near-infrared (NIR) reflectance, however, is more strongly affected by solar angle, particularly at lower angles where light interacts more with canopy structure (Lord et al., 1988). This distinction is important because vegetation indices (e.g., normalized difference vegetation index or NDVI) rely on both R and NIR reflectance.

Figure 4: a) More shadows in the foreground occur as the corn closes the canopy, while the background corn is behind in growth stages, and b) a closed soybean canopy completely shades the ground, capturing a majority of sunlight at the top of the plant (photo: Jarrod Miller).

Even in high-density crops, external shadowing can still impact reflectance. Shadows from adjacent taller crops or trees can cause overestimation of biomass (Ranson & Daughtry, 1987). To minimize these effects, care should be taken to reduce shadow interference from both within and outside the crop canopy.

Selecting the Ideal Time

Because the sun is highest in the sky at **solar noon**, the easiest way to time flights is within a window around this time. This minimizes variations in solar

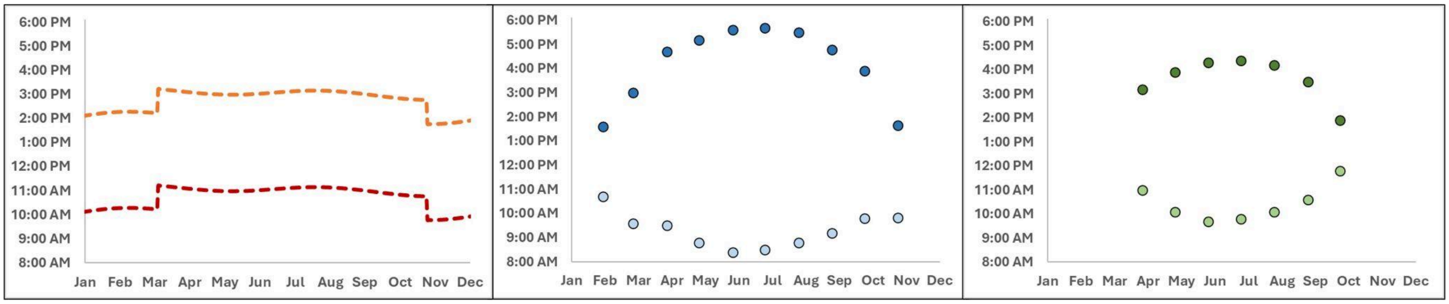

Figure 5: a) a two hour window around solar noon (not 12 p.m. necessarily, b) the window of 30° solar angles in Delaware, and c) the window of 45° solar angles in Delaware. No data for any month means the sun does not move above that angle.

angle, reducing the impact of shadows and ensuring more consistent reflectance measurements. A common guideline is to fly within **two hours** of solar noon, though specific timing may depend on location, season, and crop characteristics. Solar noon is not exactly 12 p.m., it varies throughout the year, and may depend on daylight savings time. In Figure 5 you can visualize this two hour window around solar noon, which has a shift in March when daylight savings sets in. During daylight saving time, the four-hour window runs from 11 a..m. to 3 p.m. otherwise, it is from 10 a.m. to 2 p.m. during the winter months.

However, this window is approximate and does not actually measure solar angles, which also change with the season. During winter, the sun appears lower in the sky, making the optimal flight window smaller during the day, while in summer, the higher sun position extends the ideal period over a larger window. This leads to the question: What is the best minimum solar angle for mapping crops?

For corn, it has been found to be insensitive to solar angles between 30 and 65°, particularly when at full canopy (Lord et al., 1988). Reflectance spread for both corn and soybean has also been more stable at solar angles above 40° (Souza et al., 2010; Kollenkark, J.C.). For tallgrass prairies, solar angles of 45° have produced the strongest relationship between NDVI and LAI (Middleton, 1991). Alternatively, for measuring seagrass habitats, recommended sun angles are less than 40° (Nahirnick et al., 2018). Therefore we have created two additional graphs showing the extreme lower sun angle (30°) and potential ideal sun angle (45°) in Figure 5b and 5c. In Delaware, we don't achieve 45° solar angles until April through October (Figure 5c), so this ideal condition is limited to the summer crop season. In April, the optimal flight window is roughly 2 hours around solar noon, but it can extend from 10 a.m. to 4 p.m. in June and July.

For 30° solar angles, the window is much wider, with winter months roughly correlating to the two-hour window around solar noon. This window can stretch from 9 a.m. to 5 p.m. in June and July. However, caution should be taken with these very low angles, as shadows from trees and adjacent crops will be more prevalent (Figure 6). As summer provides more opportunities for higher sun angles, flights after 10 a.m. would still be recommended. The 30° baseline is probably best suited for winter months when there are fewer opportunities for flights with higher solar angles.

Figure 6: On the left are tree shadows in a visible image, creating patterns in the NDVI image on the right, which takes up a smaller portion than the shadow cast in the visual image.

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