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Challenges in the Planning, Construction and Farming Practices in Agrivoltaic Systems With Vertically Mounted Panels

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Abstract. Several challenges in planning, construction, and farming practices hinder the optimization of agrivoltaic systems (AS) and the achievement of optimal crop production. This paper identifies and addresses these issues while presenting initial solutions. One specific type of AS involves vertically mounted panels on arable or grassland sites. The installation of panel rows divides large fields into narrow units, restricting the use of farming implements with different working widths. Implement widths must align with the spacing between panel rows, which often results in residual strips or overlapping issues when field operations are carried out. Furthermore, boundary effects in AS are more pronounced, impacting yield along field borders. The presence of panel rows also complicates driving operations, requiring reduced speeds and posing collision risks between implements and panels. Soil compaction during AS construction, microclimate variations, and panel contamination by dust, or spray drift deposits further affect plant growth and solar system performance. Initial solutions are proposed to address these challenges. These include careful planning of row spacing based on the working widths of critical implements such as combines, adoption of field sprayers with foldable booms, consideration of pneumatic fertilizer spreaders, and integration of precision farming techniques to manage variability within AS. Additionally, the use of construction machinery with low soil pressure, employment of steering technologies based on global navigation satellite systems, and research on panel cleaning devices are suggested. Overall, this paper highlights the need for further research and development to overcome farming challenges in agrivoltaic systems with vertically mounted panels.

Keywords: Agrivoltaic Systems, Vertically Mounted Panels, Planning, Construction, Farming Practices

1 Introduction

For agrivoltaic systems (“AS”), there are many various types that have different characteristics [1, 2]. Research and development work is being carried out in the various fields to optimize the systems and improve the production of the crops in the AS. Systems with vertically mounted panels are among the types of systems which can be used on arable land or grassland sites [1] (Fig. 1).

Figure 1. Research agrivoltaic system of the University of Applied Science Dresden.

A look at the science shows that for this type, as well as others, certain issues have received too little attention. These include planning, construction and, most importantly, farming practices. As a result, significant problems remain in these three areas, and optimal farming is far from being achieved. This paper defines and designates these problems and presents initial solutions.

2 Initial conditions

In many countries around the world, such as in Europe, small fields have been combined into large units over the past decades. This means that these areas can be cultivated quickly and efficiently with large machines. If an agrivoltaic system with vertically mounted panels is now installed on a field, the individual panel rows divide the large field into many small, narrow units (Fig. 2).

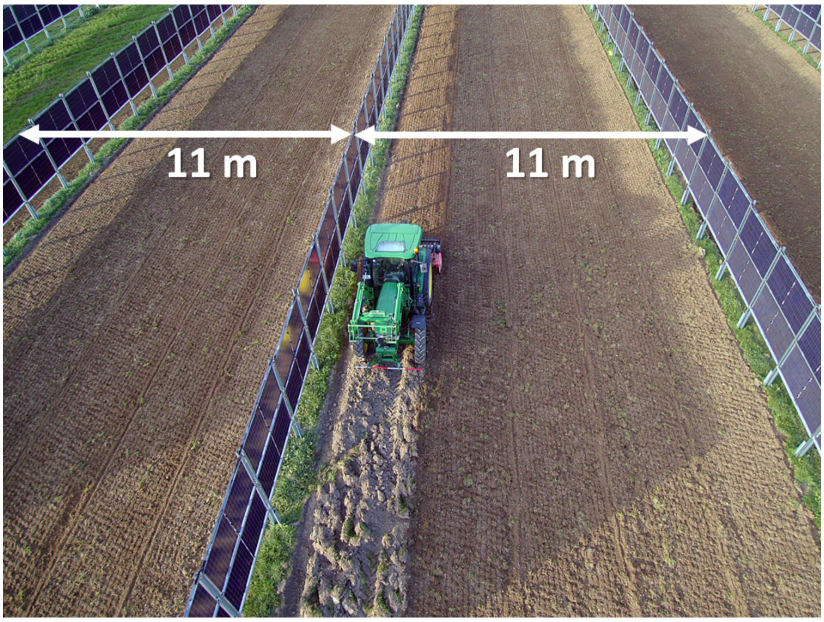

Figure 2. Panel row spacing in the agrivoltaic system of the University of Applied Sciences Dresden.

With typical panel row spacing of 10 -12 m, the width of these narrow field strips is only about 9 -11 m (due to the usage of a strip of 1 m for a row of panels).

3 Problem description

On a farm, the individual implements have different working widths. This results from the fact that different tractor engine power is required per meter of working width for the individual field operations. Therefore, implements with a high power requirement have a smaller working width (e.g. plow) than implements with a low one (e.g. seeding machines).

Figure 3 shows the working widths of various machines as they occur on a larger farm in Germany.

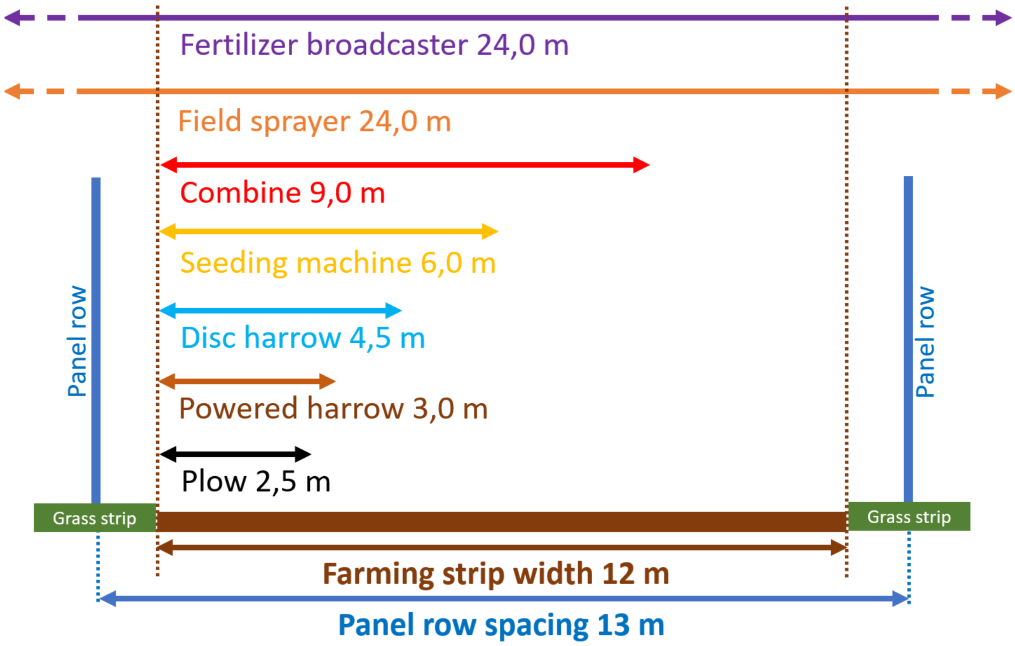

Figure 3. Typical working widths of implements of a larger farm in Germany drawn between two rows of panels.

At first glance, it is already obvious that the fertilizer broadcaster and the field sprayer with these working widths can no longer be used in the AS. From an economic point of view, it does not make much sense to purchase smaller equipment only for the working in the AS, since AS often have an area of only a few hectares and thus a sufficient utilization would not be given. With disc fertilizer spreaders, it is often possible to reduce the working width down to 12 m. The problem here, however, is that a complete overlap of the spreading sections is required and therefore the throwing width is about twice as large as the working width. This is not feasible in the AS, as the panels would interfere with the trajectories of the fertilizer grains.

The combine fits between the rows of modules, but a residual strip of about three meters remains, which must be harvested with an additional pass. For the seeding machine it would fit well, since two passes would give 12 m. When it comes to tillage, it is more complicated. In purely mathematical terms, e.g. with the powered harrow, four passes would result in 12 m, but since the individual passes must overlap somewhat (to prevent unworked strips from being left behind), a narrow residual strip would still remain. While no overlap is required with the plow, the typical design of most plows makes it impossible to get sufficiently close to the row of panels.

Boundary effects are another problem. Along the field borders, yields are lower in most fields than in the central area of the field [3, 4]. The reason for this is, for example, a lower nutrient supply. This is often due to the fertilizer spreader, which cannot deposit a sufficient amount of fertilizer at the edge of the field. In a regular field, this does not play a major role. In an agrivoltaic system, however, this can be problematic because this boundary stripes area has a much larger share than in a regular field of the same size (Fig. 4).

Figure 4. Edge stripes (in blue color) in an agrivoltaic system.

To illustrate this, here is a calculation using an example:

Field size: 5 ha Length: 250 m Width: 200 m
Assumed width of the edge strip: 1 m

Regular field: 2 edge stripes (left and right side of field)
Area of edge stripes = 2 x 250 m x 1 m = 500 m2 = **1 % of field area** (1)

Field with agrivoltaic system: row spacing 10 m ==> 40 edge stripes
Area of edge stripes = 40 x 250 m x 1 m = 10.000 m2 = **20 % of field area** (2)

This example clearly shows the serious proportion of area that the edge strips can have in an AS.

Basically, the rows of panels make the driving more difficult. Usually, the driving speed in an AS has to be reduced for many operations. The passes are sometimes very close to a row of panels, so that at the regular speeds, small driving errors can very easily lead to a collision between the implement and the row of panels, and thus to damage. But reducing the driving speed reduces the field efficiency. In addition, in some cases by reducing the driving speed, this can mean that a good working result is no longer achieved (e.g. with the cultivator, which must be employed at a speed of more than 10 km/h).

One problem with the construction of the agrivoltaic system is the risk of soil compaction, which can then severely interfere with plant growth. As could be seen during the construction of our own AS, construction companies would use the same vehicles and machines for the construction of an AS as they would use for the construction of regular ground-mounted solar plants. In addition, the soil moisture is not observed. These construction vehicles often exert pressures of 300 kPa and more on the soil, leading to soil compaction, especially in wet soils [5, 6, 7].

Soil and weather exert a very strong influence on plant growth. The panels add another influencing factor. They create different microclimate zones in a field which can lead to different nutrient and water supplies, different disease and pest infestations and thus to changes in plant growth [8, 9, 10].

Another problem can be deposits on the panels caused by crop production. This may be dust generated during soil cultivation, seeding, chopping, hay baling or combine harvesting [11, 12]. There are already numerous studies on the deposition of dust on panels and its effects as well as possibilities for cleaning [13, 14, 15]. However, none could be found that refers to an AS with vertically installed panels. During the application of chemicals like pesticides, e.g. with a field sprayer, there is always a risk of spray drift and deposits on the panels. There are also numerous studies on drift, but none could be found with respect to vertically installed panels in an AS. Therefore, no statements can be made about the effects (damage and solar power production) of agricultural chemicals on the solar panels.

4 Initial solutions

When planning an AS, the farmer must first determine which spacing between rows of solar panels is right for his farm. This involves identifying all the equipment in his machine park that he needs for crop production in the agrivoltaic system. The most important variable here is the working width. At the same time, he must also record the total width of the equipment, as this is often greater than the working width. For determining the spacing between rows of solar panels, the focus should first be on the harvesting machines, such as the combine. Avoiding additional passes due to improper spacing is of greater importance, as these harvesting machines and their use are very costly compared to other implements [16]. Therefore, the spacing between rows of solar panels should correspond to the combine working width or, in the case of smaller working widths, to an integer multiple of the working width. However, if most of the other machines would do better with a different spacing, then a more detailed cost and operating time analysis of the use of all implements must be performed. This will help to find out which additional passes of the various implements lead to the lowest operating costs [16]. Nevertheless, it is necessary to develop algorithms that help to determine the panel row spacing more easily and optimally.

First solutions are emerging for field sprayers with large working widths that no longer fit between the rows of solar panels. There are already manufacturers who offer booms for field sprayers that allow spraying with partially folded booms on both sides [17]. With the resulting smaller width, these field sprayers could be used between rows of panels.

Despite intensive planning, it will also often be difficult to determine a suitable row spacing due to the variety of different machine working widths on a given farm. Therefore, it will be necessary to purchase new machines, rent them, have contractors carry out certain operations or accept additional passes.

In order to minimize boundary effects in nutrient supply, so-called pneumatic fertilizer spreaders would be very helpful [18]. These are currently commercially available only in large working widths [19]. Research and development work on smaller devices that would be useful for agrivoltaic systems has been done, but there are no market-ready devices yet [19]. Temporarily, disc fertilizer spreaders with a very good boundary spreading device can be employed [20].

For farmers who still steer their tractors by hand, a decision must be made at this point as to whether they want to continue steering manually or switch to steering based on Global Navigation Satellite Systems ("GNSS", e.g. "GPS"). With precision steering with an accuracy of about +/- 1 to 2 cm (e.g. "RTK-GPS"), overlaps can be reduced to about 3-5 cm during tillage [21]. Thus, the issue of vehicle steering also has an impact on the determination on spacing between rows of solar panels. In addition, with precision steering no reduction of the driving speed is necessary when driving along the panel rows.

In order to avoid soil compaction during the construction of the AS, construction machinery or vehicles that exert a low soil pressure are to be used. These include vehicles with rubber track drives, tractors with wide tires or dual wheels [6, 7]. In addition, only dry soils should be driven on.

Since the development of microclimates in an AS variability is even greater than is already present in a regular field, more attention must be paid to variability in crop production. A standard way to deal with variability in a field is precision farming [22]. This involves dividing a field into small-scale management zones, which are then managed individually. This means that tillage, seeding, fertilization and crop protection are carried out site-specifically.

With regard to damage caused by stones, dust or spray drift deposits, no results could be found. There is a need for further research in these areas. If precipitation is not enough to clean the panels in case of contamination with dust or spray drift, it makes sense to develop cleaning devices, e.g. based on self-propelled robots.

5 Conclusions

So far, the development of agrivoltaic systems has focused primarily on "voltaic" and less on "agri". Therefore, agricultural production does not yet work as would be desirable for farmers. In general, there are still many open questions regarding farming in agrivoltaic systems with vertically mounted panels. These need to be clarified so that acceptance among farmers will continue to increase and more AS will be built.

Data availability statement

There is no data available.

Author contributions

Karl Wild: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Writing - Original Draft, Visualization, Supervision, Project administration, Funding acquisition; **John K. Schueller:** Methodology, Investigation, Writing - Review & Editing

Competing interests

The authors declare no competing interests.

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