8 DS ANALYSIS & AI SCENARIOS FOR COMP DS IN TUNISIA

The set of figures produced for the Tunisia case study offers a multi-layered analytical perspective on irrigation performance and WEFE interactions across the **three selected scenarios: S1 (Drip Irrigation - Day), S3 (Drip Irrigation - Night), and S5 (Subsurface Irrigation).** These visualizations integrate temporal behavior (monthly water requirements), efficiency indicators, and aggregated WEFE scoring to evaluate the trade-offs and synergies inherent in each irrigation strategy under semi-arid climatic conditions.

The **monthly NIR (Net Irrigation Requirement)** bar chart (Figure 49, below) reveals the internal hydrological structure of the system. Scenarios S1 and S3 produce identical monthly NIR distributions, demonstrating that the time of application (day versus night) does not alter the crop's physiological demand nor the water balance in the NECADA simulation environment. This invariance confirms that evapotranspirative forcing—not irrigation timing—dominates water demand at this location. Scenario S5, by contrast, shows a marked depression in NIR across the entire irrigation season, with the strongest reductions occurring in the peak evapotranspiration months (June–August). This **reduction (~38.5% annually) reflects the intrinsic capacity of subsurface irrigation to suppress soil-surface evaporation and to maintain higher soil moisture retention**. The structure of monthly reductions indicates that subsurface application is most efficient when evaporative demand is highest, reinforcing its value in climate-stressed Mediterranean environments.

The **monthly GIR (Gross Irrigation Requirement)** bar chart (Figure 49, above) replicates the same seasonal pattern but accounts for irrigation system efficiencies. Once again, S1 and S3 behave identically, while **S5 demonstrates a significant decline in required applied water.** Because GIR is the operational quantity defining pumping energy, system sizing, and seasonal water demand, this reduction carries direct implications for hydrological sustainability, energy consumption, and GHG emissions. The shape of the GIR curve highlights how inefficient surface application becomes during peak climatic stress, whereas subsurface irrigation minimizes hydrological losses through deeper-point delivery.

The **WEFE radar diagram** (Figure 50) **provides a multi-criteria assessment** synthesizing water efficiency (inverted GIR and NIR indicators) and food productivity (yield). Here, **S5 forms the most expansive polygon in the water-related axes, clearly outperforming S1 and S3**. Although S5 exhibits a modest yield reduction relative to S1 and S3 (2.32 t/ha vs. 2.67 t/ha), the **magnitude of water savings more than compensates within a WEFE logic, resulting in superior integrative performance**. Because S1 and S3 share identical water performance and identical yields, their radar footprints overlap entirely, demonstrating once again that the temporal shift in irrigation does not translate into WEFE-relevant differences.

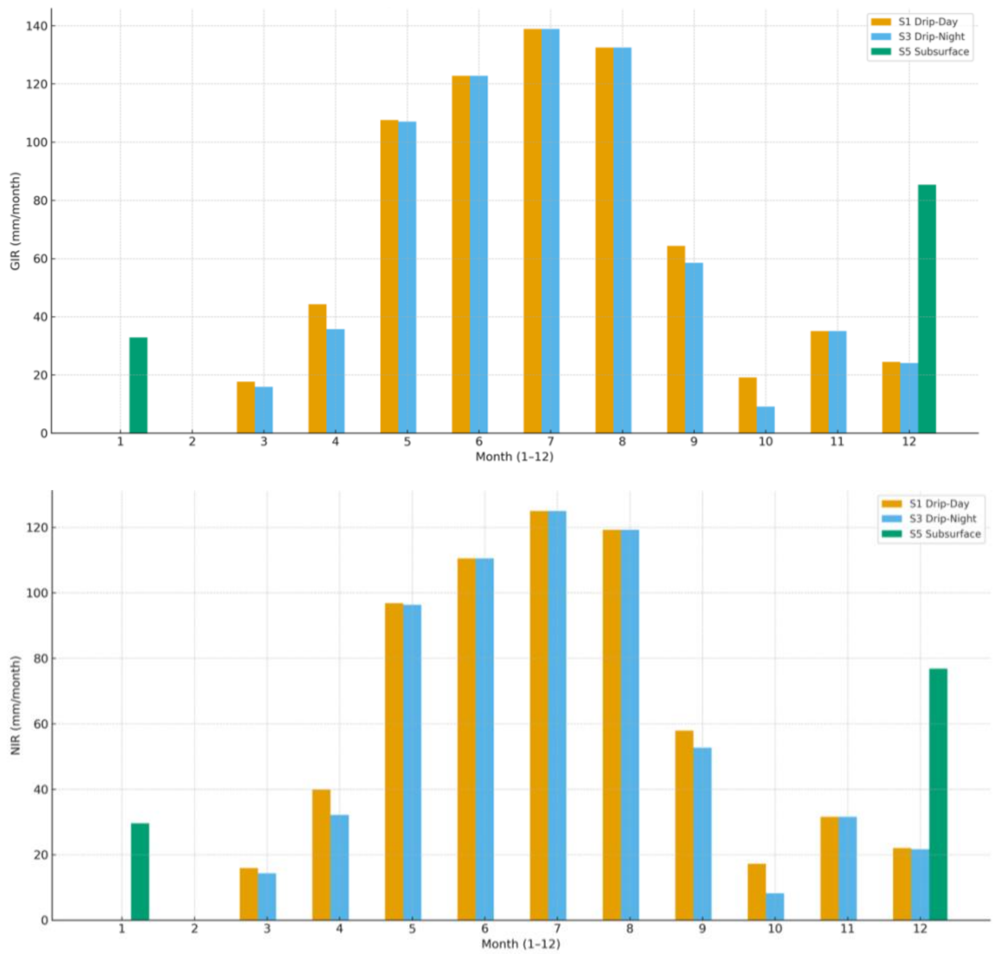

FIGURE 49. NIR AND GIR DATA (MM /MONTH) FOR TUNISIA DEMOSITE ACCORDING TO THE DIFFERENT SCENARIOS (S1, DRIP IRRIGATION DURING DAY; S2, DRIP IRRIGATION DURING NIGHT; S5, UNDERGROUND IRRIGATION).

The radar diagram therefore reveals the structural hierarchy between the irrigation methods: **surface irrigation provides higher yields but at the expense of water and energy, whereas subsurface irrigation optimizes WEFE performance in a resource-efficient manner.**

The WEFE Composite Index heatmap (Figure 51)Figure 44 operationalizes this comparison into a quantitative metric. After normalizing each axis—WaterEff_GIR, WaterEff_NIR, and FoodEff—the composite index confirms that S5 is the highest-performing irrigation strategy. The WEFE score for S5 remains elevated because the improvements in water-related metrics (~39% reduction in both GIR and NIR) have a stronger influence on the integrated index than the yield penalty. In contrast, S1 and S3 achieve high food efficiency but low water efficiency, resulting in noticeably lower composite values. Because the composite index integrates all WEFE dimensions with equal weight, it highlights resource-use optimization rather than yield maximization alone

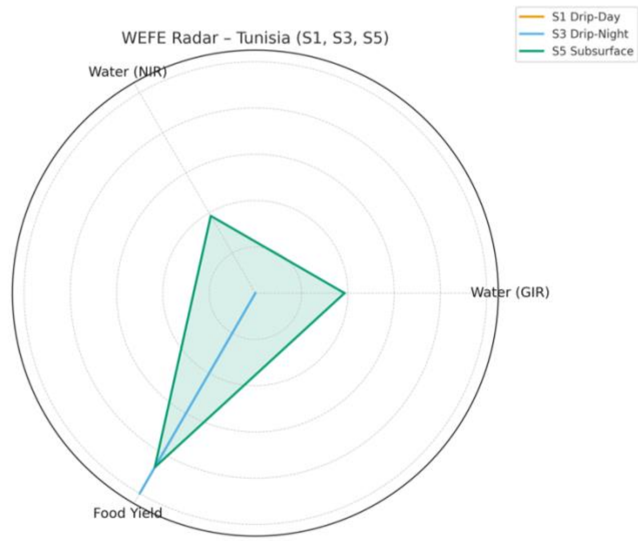

FIGURE 50. WEFE RADAR DIAGRAM FOR S1, S2 AND S5 SCENARIOS AT TUNISIA.

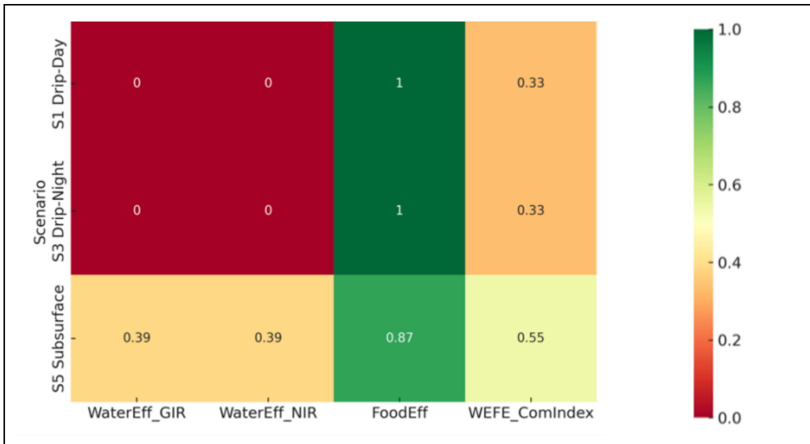

FIGURE 51. HEATMAP OF THE WEFE COMPOSITE INDEX FOR S1, S3 AND S5 SCENARIOS.

8.1 AI WEFE Nexus Trade-off Analysis for Tunisia

In Figure 52, a **Δ-heatmap illustrates the marginal gains or losses of each scenario relative to the baseline S1.** By applying the same green–yellow–red palette as the composite index, the Δ-heatmap precisely conveys the direction and magnitude of scenario deviations. **S5 shows strong positive deltas for both water-efficiency axes, indicating major performance improvements**, while presenting a small negative delta for food productivity.

The net improvement in the WEFE composite index (+0.21) demonstrates that **water savings outweigh the loss in yield.** S3 shows nearly zero deltas across all metrics, confirming that S1 and S3 are functionally equivalent from a WEFE standpoint. The Δ-heatmap, therefore, provides a transparent visualization of trade-offs, emphasizing that **S5 occupies the most favourable region of the WEFE trade-off space.**

Together, these figures build a cohesive narrative: **subsurface irrigation (S5) is the most WEFE-efficient solution for semi-arid Tunisia.** It significantly reduces water use, lowers system losses, improves water- and energy-efficiency indicators, and delivers a balanced level of productivity. **Surface drip methods (S1 and S3) remain yield-maximizing but impose higher pressures on water and energy systems, rendering them less optimal in a WEFE-integrated assessment.**

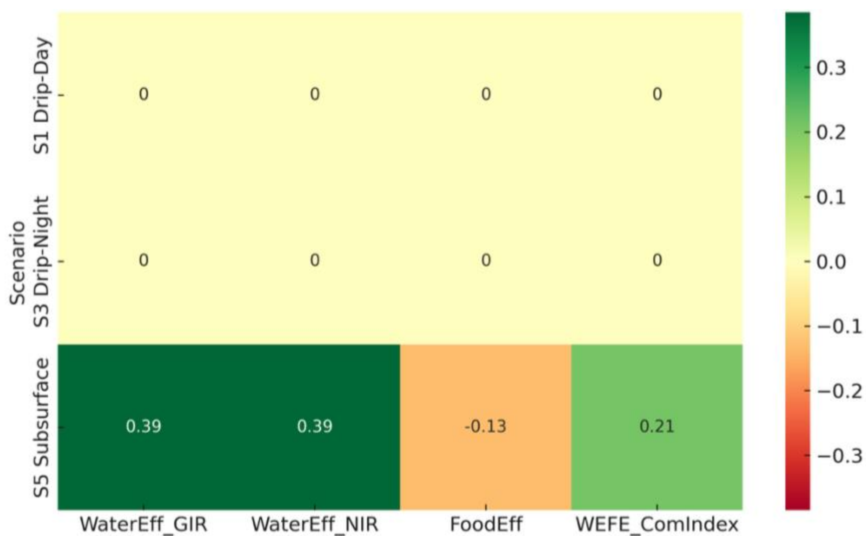

FIGURE 52. WEFE TRADE-OFFS VS S1 REPRESENTED BY A DELTA HEATMAP (GREEN = IMPROVEMENT).

The delta heatmap confirms that the **agrovoltaic scenario (S1) offers substantial water-efficiency gains while maintaining acceptable food performance.** When integrated through the WEFE composite index, the overall system performance improves, demonstrating the multi-benefit nature of agrovoltaic systems in the Mediterranean context.

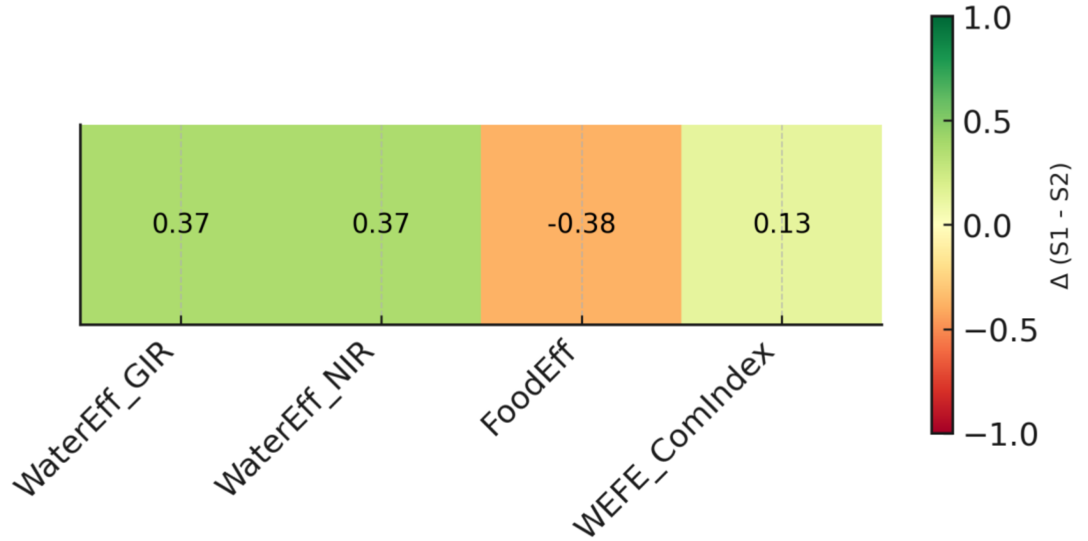

Figure 53. Delta Heatmap for agrovoltaic system.