PhoenixBot: Towards an ecological weed management robotic system

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I. Introduction

Our global food systems face a critical juncture. We must significantly increase global food production to keep pace with a growing population while simultaneously mitigating the harmful environmental effects caused by our mainstream unsustainable farming practices [1]. We propose that robotic agricultural systems could play a vital role in addressing the perceived trade-off between environmental sustainability and increased crop yields [3]. Our work focuses primarily on enabling sustainable weed management practices on farms.

While robotic systems have been developed for automated weed management, current solutions often lead to unintended negative environmental and ecological effects. Most existing systems rely on either precise herbicide spraying (spot spraying), which still involves the use of harmful chemicals, or on significant tillage, which negatively affects soil health [1, 5]. Additionally, an emphasis on monocultures in existing systems severely restricts biodiversity and has implications for soil quality.

Ecological Weed Management (EWM) — provides sustainable alternatives to conventional weed control. It challenges the notion that all non-crop plants are harmful, emphasizing an agroecological viewpoint that some non-crop plants are beneficial [3, 6]. In fact, studies suggest that well-managed weed biodiversity can even increase crop yields [2].

II. The PhoenixBot Framework

This ongoing work proposes a hybrid robotic system, **PhoenixBot**, inspired by [2, 6] and rooted in EWM, aimed at achieving sustainable weed management while simultaneously maintaining or enhancing crop yields. This proposed system eliminates herbicide use, minimizes soil inversion and selectively regulates non-crop populations on the farm. Its potential benefits include positive impacts on biodiversity, soil health, and overall crop productivity.

The PhoenixBot system (Fig. 1) comprises 3 components:

- The **AerialBot**, an unmanned aerial vehicle (UAV), captures high-resolution aerial images of the farmland routinely. These images are used for plant species identification and for generating weed and yield maps.
- The **GroundBot**, an all-electric autonomous micro-tractor (the *farm-ng* Amiga system), traverses the farm (through GPS-guided path following) and is equipped with a **WeedPlucker**, a custom-built delta configuration robot manipulator with an end-effector gripper to mechanically uproot weeds with minimal soil inversion.

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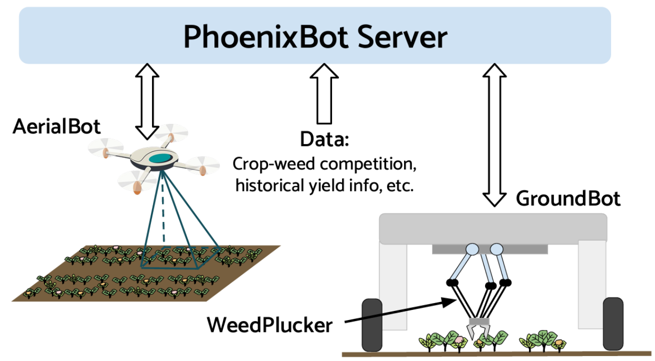

Fig. 1: The PhoenixBot system with its three key components: the PhoenixBot server, the AerialBot and the GroundBot (with the WeedPlucker).

- The **PhoenixBot Server** is the central processing and control unit. It processes aerial images (from the AerialBot) using deep learning-based plant-species identification to generate a field map outlining crop and non-crop plant distributions (also known as weed and yield maps) [4]. As proposed by Merfield [6], these data are synthesized with historical yield and crop-weed competition information [2, 3] to determine appropriate local weed species population thresholds at a plant species-specific level. Using the population threshold information, the PhoenixBot Server determines which non-crop plant species to target for weeding at a site-specific level to limit crop competition. This information is sent to the GroundBot for real-time weeding at a plant-specific level.

We hypothesize that our proposed system, which enables ecologically-sensitive plant species-specific weed management, holds the potential to unlock the next paradigm of robotics-driven environmentally sustainable weed management practices.

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