Weed Management

Trialling autonomous under-vine weed management in Australian vineyards

Over the last two years AWRI Engineers **Simon Nordestgaard** and **Denny Hsieh** have been investigating autonomous under-vine weed management. In this article they share their experiences and results.

Introduction

There is pressure to reduce the use of herbicides such as glyphosate in vineyards around the world. Mechanical alternatives for under-vine weed management such as cultivation and mowing require more and slower tractor passes with correspondingly higher labour requirements and costs. One option is to perform these operations autonomously.

The AWRI received a grant from the Australian Government's Established Pest Animals and Weeds Management Pipeline Program to assess the performance of autonomous vehicles for under-vine weed management in Australian vineyards. The project aimed to trial an autonomy-kit retrofitted to a tractor in conjunction with various implements, a French under-vine weeding robot and autonomous lawnmowers, working with an industry collaborator. The insights gained from the project also apply to the use of autonomous vehicles in vineyards for other tasks.

GOtrack tractor autonomy-kit

The first autonomy-kit for an Australian vineyard tractor was imported as part of the project. The system was from GOtrack in Poland and was fitted to our industry collaborator's Fendt 211P Vario tractor in 2021. The kit came with good instructions, and it was possible to fit it to the tractor over the course of several days with a little remote support from the manufacturer via WhatsApp. This process would be even easier now, as there is an Australian distributor who likely performs new installations. The kit was designed for the specific tractor model and took advantage of various existing conduits and mounting points on that model. However, many of the same base components (steering wheel drive, brake drive, antenna bar, safety bumper, etc.) would be common to any tractor and they are installed by GOtrack in slightly different configurations on other tractor models (Figure 1).

The GOtrack system (and most other autonomous farming solutions) operates primarily based on satellite positioning (GPS and other constellations) in conjunction with a local real-time kinematic (RTK) correction source that upgrades the positioning from the ~5 m accuracy typical on a mobile phone to the ~3 cm accuracy needed to drive a vehicle autonomously. Our collaborator had their own RTK base station broadcasting corrections via NTRIP (which allows corrections to be received via the internet) and this was the main correction source used for trials, but we did also successfully operate the system using RTK network subscription services. Cellular phone coverage was needed for the system to be able to access the RTK corrections and for remote communication with the vehicle. It may now also be possible to operate this and similar systems in areas without phone coverage using SpaceX's Starlink service, but this has not been tested.

The GOtrack system currently works primarily by record and playback. A route is recorded by driving the tractor and that route can then be played back when desired. The vineyard does not need to be otherwise mapped. Key actions such as when the power take-off (PTO) is turned on and off and when the rear hitch is lowered and raised are recorded as part of the route. Hydraulic tools can be used, but they cannot be turned on or off during autonomous operation (this functionality may come in the future). In conjunction with a supplied receiver, spray units can also be turned on and off and this can be recorded as part of the program. Spraying was successfully performed but was not a focus of the current project. Recorded routes can be started and stopped using text messages or a mobile phone app once the vehicle is lined up on the route.

Early in the project, routes were recorded to run different under-vine weeding equipment, and these were successfully later played back (e.g. Figure 2). Generally, the under-vine weeding routes trialled covered 2-3 ha (a range of different styles of equipment were used on different treatment areas). To test the system's endurance, much longer mid-row slashing runs were also performed, covering areas of around 15 ha. This was about the largest route that it was possible to record (but many routes of this size could be stored in the system). Generally, for these larger routes they were recorded in smaller sub-sections every couple of hours of driving, and these were later merged to generate the final route for a block. We would still like to test additional long routes later in the growing season in heavy sprawling canopies that may obscure communications to verify sustained performance under these circumstances.

Routes were played back at 1.5-10 km/hr depending on the implement used and the vineyard conditions. Generally, operations can be performed at a speed of around 5 km/hr for a sustained period, unless the implement necessitates slower speeds. For example, some of the under-vine weeding tools need to be operated at around 2.5 km/hr regardless of whether they are operated manually or autonomously if they are to do a good job and not leave excessive weeds around the vine trunks and posts. Mid-row slashing was performed at up to 10 km/hr, but there is much more likelihood of clipping vines and posts at this speed than at 5 km/hr - ultimately the speed chosen will involve trade-offs between how quickly work can be performed and how much

Figure 1. Fendt 211P Vario tractor with GOtrack autonomy-kit fitted: (a) with bump sensor, stop buttons, LIDAR and GNSS-RTK antenna bar (b) Steering-wheel drive (c) Brake drive

damage is caused as well as how often the machine stops and needs to be restarted.

Speeds of around 1.5-2 km/hr were generally used for cornering because that is the time where the system is most likely to have issues getting off-line and a slower speed gives the system time to manoeuvre and correct its path. Similarly, best operation was achieved by using a pattern of driving down every third-row, as this prevents turns from being too tight, although we have also successfully driven patterns working every second-row. Routes are set up to eventually cover every row in the block.

The system worked well for basic operations such as slashing, cultivation and spraying (although we have not performed spraying on long routes). We have also not tested operations such as trimming and pre-pruning, as these likely require more complex operator control, and use sharp, often front-mounted tools that present greater safety risks during autonomous operation.

Obstacle detection

The GOtrack system was initially supplied with a basic LIDAR for obstacle detection. When operating in pruned vineyards and neat mid-rows it was possible to use settings so that the LIDAR would always stop the tractor for a person or vehicle ahead of it. However, as the canopy and grass grew, these started to cause a lot of false stops. The LIDAR is purely a safety sensor and could be disconnected if other safety measures are in place. Generally, we believe that large autonomous vehicles should not be operating at the same time that people are working in vineyards anyway, but it still seems desirable to have a back-up sensor system (for example, so it stops when a trespasser decides to try and get a selfie of themselves in front of a driverless tractor).

In June 2023, GOtrack supplied a new camera obstacle detection system (Figure 3). This has built-in models to detect people, cars and other objects. It is not reliant on people having to wear high-vis vests or carry safety devices. This seems like a sensible approach. It will likely still need further training to be able to recognise other equipment that might be encountered in vineyards such as tractors and grape harvesters. We have also yet to test it out working among large canopies. It seems unlikely that these and other sensors on the market are going to be able to detect people if they are wilfully hiding in the canopy. However, the GOtrack system does also have a bump sensor and stop buttons and the tools are mounted behind the tractor, which seem like appropriate risk-mitigation strategies in conjunction

Figure 2. Autonomous under-vine mowing using the tractor fitted with the GOtrack autonomy-kit

with measures to ensure that people are not allowed in the vineyard during autonomous operation.

Implement suitability and integration

Tractor implements have typically been designed assuming that there will be someone in the tractor who will be able to stop the vehicle and deal with any implement issues that might arise – for example, a hydraulic oil leak or a wire wrapped around a slasher. Sustained autonomous operation therefore needs sensors on implements to shut the tractor down and notify the owner when something goes wrong before much damage is done.

For hydraulic under-vine weeding tools, we found pressure sensors in the hydraulic return lines to be quite good for diagnosing issues such as hydraulic leaks or tools binding up. We also experimented with proximity sensors for rotating tools to monitor their speed. Initially this was performed with a stand-alone data logger, but now GOtrack has modified the programming for the receiver provided to control sprayers to also work with standard industrial sensors on other tools. This is still in the early stages of development, but it is a logical solution. Conceivably, most implements will need a few basic sensors to detect common failure modes and shut the system down.

Some tools are inherently more suited to autonomy than others. For example, for under-vine cultivation, under-vine blades and mowers that have sensor rods that are designed to retract the tool around the posts and vines allow the vehicle to be quite a long way off-line without consequence. However, tools such as roller hoes (rollhacke) that are in a fixed position close to the vines have little room for error and if they are used for long enough autonomously it is likely that the vehicle will go off-line enough for these to catch and embed themselves in a post or vine. This will still usually be managed by the system indirectly, as the tractor will be dragged far enough off-line to trigger an off-path shut-down or into the vines such that the bumper sensor triggers a shut-down, but a few vines and posts might be damaged in the process. Interestingly, online videos of vineyard weeding robots often feature

Figure 3. GOtrack (a) obstacle detection camera (b) live camera view testing object recognition, and (c) cab view after detecting a person and stopping during actual operation (safety driver in place)

roller hoes. One difference appears to be that while we were generally using them on an implement frame behind a tractor cultivating one-side of two rows, in the videos they are generally used on a straddle robot cultivating both sides of a single row.

SITIA Trektor

As part of the project, we had originally intended to rent a Vitibot Bakus or Naïo Ted vineyard weeding robot. These are apparently the pre-eminent vineyard robots in France. However, the suppliers decided at that time to focus their efforts on the European and US markets rather than coming to Australia. Instead, we rented another French robot, the SITIA Trektor (Figure 4), which has also been quite prominent online and at tradeshows and of which one had recently been sold in Australia.

While our experiences with the GOtrack were mostly positive, our experiences with the SITIA Trektor were generally disappointing. While some short demonstrations were ultimately able to be performed, the machine had many bugs and issues that meant it was not practically usable in our application, despite much time and effort working with the manufacturer.

The width and height of the machine are adjustable, and the machine is designed to work either between rows or straddling a row; however the height was not able to be raised enough to allow straddle operation in typical Australian vineyards, so it could only be used between rows. The machine has bump sensors above the left and front wheels and once a sprawling canopy had developed these caught on the canopy and triggered stops repeatedly (Figure 4b). The system also had a LIDAR and a camera, but these were not operational.

Building a robust agricultural vehicle is not easy, and the autonomy is perhaps less challenging than building the vehicle.

The system used skid-steering and had large caster wheels on the front. This arrangement allowed it to drive very accurately autonomously and turn very tightly – it could go back down the very next row – but the skid steering and casters were not very good when the vehicle got bogged and the propensity to get stuck was exacerbated by its skinny tyres (some overseas installations have wider tyres). The steering system and casters also made driving the vehicle up or down a ramp for transport on a trailer very precarious. The system used a games controller that was constantly running out of battery and there were often communications problems between it and the Trektor (the controller has subsequently been upgraded to a more robust design).

On many occasions the machine would not turn on or got stuck in awkward locations and had to be rescued with a telehandler. Some of these problems could be categorised as teething issues with an early prototype that will be resolved in later models, but others are related to design choices that do not suit Australian vineyards.

Tractor autonomy-kits versus robots

Our experiences with the GOtrack system fitted to a Fendt tractor (an established proven tractor brand) versus the SITIA Trektor brought to our attention that building a robust agricultural vehicle is not easy, and that autonomy is perhaps less challenging than building the vehicle. On that basis, a retrofit-kit for a proven tractor design seems like a very sensible approach. That is not to say that other companies cannot succeed building their own autonomous vehicles, but it will likely require significant skills and experience in agricultural vehicle design. Another advantage of using a tractor with a retrofitted autonomy-kit is that it can continue to be used as a normal tractor, including driving it on public roads between blocks.

One downside of autonomy-kits is that normal tractors are not designed explicitly for autonomous operation and neither are the implements that are used with them. Modifying tractors for autonomous use may also create issues with support from some dealers. The easiest solution for most growers would be if the major tractor manufacturers offered their own integrated autonomy solutions including sensor systems for common vineyard tools, but this is likely still several years away. While the tractor manufacturers have staff with the right technical skills, they are large companies and are therefore inherently risk averse. This is exacerbated by evolving regulatory frameworks for autonomous vehicles that differ around the world. Vineyard tractors also only make up a small proportion of their overall sales.

Figure 4. SITIA Trektor with mid-mount blade weeding tools (a) turning into the next row, and (b) bump sensors activated by the sprawling canopy

Autonomous lawnmowers

Autonomous electric lawnmowers are becoming increasingly common for managing domestic and commercial lawns, and we were interested to test them out as another means of managing under-vine weeds in vineyards. Two styles of Husqvarna Automower were trialled in conjunction with solar battery stations to achieve an off-grid solution (Figure 5). Irrigation lines were raised to allow passage of the Automowers across rows.

A commercial grade Husqvarna 550 Automower was installed first. Like typical autonomous lawnmowers it relied on a boundary wire to set the operational area. These mowers use light-duty sharp blades and work based on very regular operation. The test vineyard had many canes on the ground that the mower could not cut. It would drive over most of them, but eventually a cane would get caught and it would stop the Automower. The canes were therefore cleared from the vineyard to allow continued testing. The test vineyard had been cultivated in places and there was some mounding. The Automowers tended to get stuck on these and other obstacles because they didn't have sufficient clearance. The boundary wire was also problematic, and we managed to damage this multiple times.

The second machine trialled was a newly released Husqvarna 550 EPOS Automower. This mower did not use a boundary wire. It instead relied on satellite positioning with an RTK correction signal (supplied by a Husqvarna base station), much like the other autonomous vehicles trialled. This was far superior to the model using the boundary-wire in terms of ease of use and flexibility, but it suffered from the same shortcomings as that model when it came to managing the vineyard terrain and canes. Both models also faced major issues with the vineyard area that they could cover. Traversing large numbers of obstacles (posts and vines) means that the machine is constantly stopping and turning, greatly reducing the area it can cover, and in practice it struggled to cover more than a few rows, with coverage getting worse the more rows it needed to traverse. On a normal lawn each Automower might be able to cover around 0.5 ha, but in a vineyard it might only be able to cover 0.1-0.2 ha.

The GOtrack system worked well for basic operations such as slashing, cultivation and spraying.

Table 1. Soil management techniques performed during the 2021-2022 and 2022-2023 seasons

	Under-vine	Mid-row
1.	Herbicide	Sward
2.	No treatment	Sward
3.	Mowing	Sward
4.	Dodge plough	Disc-cultivator
5.	Blade weeder with rotary tiller	Sward
6.	Roller hoes with finger hoes	Sward

Soil and yield effects

Trials with different under-vine weeding techniques were primarily performed in a 15-ha Shiraz vineyard in the Barossa Valley. Prior to the trials, the under-vine area of the vineyard had been managed with one to two herbicide treatments per year in conjunction with a permanent sward in the mid-row that was slashed once or twice each year. The different techniques used in the trials are summarised in Table 1. Treatments were performed in sets of six rows in triplicate (i.e. 18 rows total) and two to three passes were performed for most mechanical weeding techniques. Soil analyses were performed, as well as grape and wine analysis. At the time of writing some wines from the 2023 vintage were yet to finish malolactic fermentation, after which they will be formally assessed.

Over the two years of the project funding, there were few differences between soil properties or grape or wine properties for the different treatments. The seasonal differences were much larger than any treatment effects, with the average yield being 8.3 tonnes/ha in 2023 compared with just 2.9 tonnes/ha in 2022. One clear difference was that juice YAN was significantly higher in 2023 for the area where the mid-row was cultivated compared with the other treatments that year.

We had expected to see some decrease in soil carbon levels with the under-vine cultivation treatments, but did not observe this in practice, possibly because the initial soil carbon levels were already quite low (around 1% on average).

Figure 5. Husqvarna Automower (a) charging using off-grid solar-battery station, and (b) stuck with rear wheels slipping

Conclusions

The GOtrack autonomy-kit worked well with a range of tools. Results with a SITIA Trektor and Husqvarna Automowers in a vineyard environment were not as good. There have been some major advances in obstacle detection for the GOtrack system, but more work is still needed on implement feedback. Given the opportunity, we would like to perform more work evaluating this and other systems for under-vine weeding and other applications in Australian vineyards. Testing out the ability of systems to work in regional areas without phone coverage and working on solutions for mapping of vineyards using drones to allow adoption of autonomy at scale are other areas that we would like to perform more work on.

Sustained autonomous operation therefore needs sensors on implements to shut the tractor down and notify the owner when something goes wrong before much damage is done.

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References and further reading

AWRI weed management resources. www.awri.com.au/industry_support/viticulture/weed-management

Nordestgaard, S. 2020. Autonomous vineyard robots and tractors. *Aust. N.Z. Grapegrower Winemaker* (680): 50-67.

Nordestgaard, S. 2022. History and recent developments in under-vine weeding equipment. *Aust. N.Z. Grapegrower Winemaker* (705): 50-61.

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