Herbicide resistance in perennial pasture systems – The horse has bolted

Jo Powells[1]
1 Local Land Services, PO Box 26, Cooma, NSW 2630, Australia
(jo.powells@lls.nsw.gov.au)

Summary Whilst herbicide resistance is well documented problem in cropping systems, far less is known about its presence and extent in perennial pastures. Perennial grass weeds such as serrated tussock (*Nassella trichotoma*) and African lovegrass (*Eragrostis curvula*) are particularly problematic in the Southern Tablelands of NSW, with minimal herbicide options available for control.

Following the identification of widespread resistance to flupropanate in serrated tussock on the Monaro in 2017, seed samples from African lovegrass were collected in Autumn 2020 and 2021 from locations across the Monaro region and subsequently tested for resistance to flupropanate.

Testing identified plants at multiple locations with low-high resistance levels as well as sites with plant still susceptible to flupropanate at the higher label rate (3 L ha^{-1}). Testing using lower rates of flupropanate (1.25–2 L ha^{-1}) resulted in reduced control of plants from some locations sampled. These results present further challenges for land managers struggling to control perennial grass weeds within perennial pasture systems.

Keywords Herbicide resistance, serrated tussock, African lovegrass, flupropanate

INTRODUCTION

There has been an exponential increase in the occurrence of herbicide resistance in weeds since 1975 (Heap 2022) and whilst the cropping sector has been managing these issues since the 1970s, managers of pasture-based systems have only had to contend with the issues since the early 2000s (Noble 2002).

Since their introduction into the country over 100 years ago, the perennial grasses serrated tussock (*Nassella trichotoma*) and African lovegrass (*Eragrostis curvula*) have posed ongoing challenges to graziers in their pasture systems in the tablelands of NSW. The group 0 (previously group J) herbicide flupropanate, has been the most successful and remains to be the most widely used chemical for control of these species in pastures. However, it is this over-reliance on a single herbicide that has driven the development of herbicide resistance. McLaren et al. (2008) noted that the continual use of group 0 herbicides (e.g. flupropanate) for more than 15-20 years has driven the development of herbicide resistance serrated tussock.

A survey investigating the extent of herbicide resistance in serrated tussock in 2004 identified 3 sites (2 in Victoria and 1 in New South Wales) where flupropanate resistance had developed (McLaren et al. 2008). This was the first finding of herbicide resistance in a perennial weed found predominantly in perennial pasture systems and prompted further investigations into the plant's biology and other herbicide control options.

Following the identification of this herbicide resistant serrated tussock, McLaren et al. (2010) surveyed a 5 km radius around the 3 known serrated tussock resistance sites and found that the resistance had become widespread. They concluded that land managers would have to increasingly deal with the issue of herbicide resistance and posed the question, "was the genie was out of the bottle?" when it came to resistance in perennial pasture weeds.

The Monaro Local archived reports indicate that NSW Agriculture commenced serrated tussock control trials using flupropanate in the late 1970s to early 1980s near Dalgety in the Monaro region. The herbicide remains in common use today across Australia however in recent times, limited availability of the chemical is supressing it's use.

Monaro land managers raised concerns about the efficacy of their flupropanate use in 2016, resulting in Local Land Services undertaking a multi-year project to test resistance to herbicides in serrated tussock grass. Herbicide resistance in African lovegrass was then investigated in 2020 following increasing concerns about management of the weed that was rapidly spreading across the Monaro.

MATERIALS AND METHODS

Serrated Tussock In 2016, an initial thirteen samples of serrated tussock seed were collected from sites across the Monaro region. This seed was sent to Plant Science Consulting (South Australia) and germinated with the seedlings sprayed with the herbicide flupropanate (745 g a.i. L^{-1}) at the equivalent rates of 1.25, 2 and 3 L ha^{-1}. Wetting agents were not used. Assessment of the effectiveness of herbicide control was made nine weeks after treatment based upon the percentage of plants surviving in herbicide treatments compared to the control. Plants with slight or no biomass reduction were classified as "resistant", biomass reductions of between 40-80% with plant recovery were classified as "developing resistance" and plants with full biomass suppression and plant death were classified as "susceptible". Under controlled conditions, the control seedlings grew strongly, so any reduction in growth was attributed to the impact of herbicide.

The following year, in an attempt to identify just how widespread the herbicide resistance issue may be across the region, a further forty-one seed samples were collected from additional locations across the Monaro and another 5 collected from outlying sites further north of the region that had been experiencing serrated tussock control challenges. The same methodology used in 2016 was repeated for this year's sampling and testing.

African lovegrass As part of a pilot study, seeds from African lovegrass plants were collected from twelve sites in autumn 2020 from the northern and central areas of the Monaro where the oldest and most dense populations of African lovegrass are located. Plant Science Consulting again germinated these seeds and then sprayed the seedlings at the four-leaf stage with flupropanate (745 g a.i. L^{-1}) at the equivalent rates of 1.25, 2 and 3 L ha^{-1} (no wetter was added). Assessment of the effectiveness of herbicide control was made using the same methodology as described for serrated tussock above.

This work was then expanded in 2021 with a more extensive collection of African lovegrass seeds from across the Monaro region. The same methodology used in 2020 was repeated for this second year of sampling and testing.

RESULTS

Serrated Tussock In the first year, five of the thirteen samples were found to have a high level of resistance to flupropanate with these samples originating from north and western areas of the Monaro. Increasing the rate of application of flupropanate from 1.25 to 2 and 3 L ha^{-1} did not significantly improve the control of these resistant biotypes which confirmed the high-level of resistance (it should be noted that 2 L $ha^{-1}$is the maximum on-label/ on-permit flupropanate rate for use on serrated tussock). The remaining eight samples were found to be susceptible to flupropanate.

In the second year of testing, twenty-three of the forty-six locations sampled tested had a high level of resistance to flupropanate. Fifteen further locations were identified as developing resistance and eight locations were still susceptible to the herbicide. For the locations where resistance was identified, increasing the rate of flupropanate application from 1.25 to 3 L ha^{-1} only resulted in small increases in control in most instances (e.g. 50 % control at 1.25 L ha^{-1}, 70 % control at 2 L ha^{-1} and 80 % control at 3 L ha^{-1}). However, plants from one location showed zero control at any of the rates of flupropanate used.

Table 1. Combined results for seed testing for flupropanate resistance in serrated tussock (2016-2018) and African lovegrass (2020-2021) populations collected from the Monaro region of NSW at maximum on-label control rates.

	Serrated tussock	African lovegrass
Resistant	28	7
Developing resistance	15	22
Susceptible	16	14
Total	59	43

The more widespread sampling of locations across the district revealed that localities with historical and higher densities of serrated tussock and a longer historical use of flupropanate, generally had higher instances of herbicide resistance. However, locations with plants still susceptible and with those identified as developing resistance to flupropanate were scattered consistently across the Monaro region.

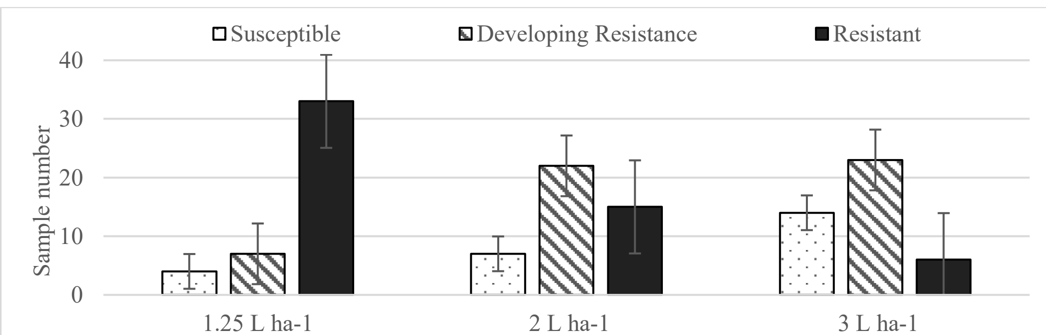

Figure 1. Resistance status of African lovegrass samples collected from the Monaro, NSW in 2020-2021 at different rates of flupropanate (745 g a.i. L^{-1}) application (standard error bars shown).

African lovegrass Of the samples collected in 2020 and 2021, seven of the forty-three locations were found to have strong resistance to flupropanate (Table 1). A further twenty-two locations showed low to mid-level resistance and fourteen locations were identified as still being susceptible to the herbicide (at the 3 L ha^{-1} rate).

At those locations where resistance was noted or was developing, many samples showed distinct responses to varying rates of herbicide application. Many showed no instances of plant death at the lower application rates of 1.25 and 2 L ha^{-1} (note that the maximum on-label rate for flupropanate application on African lovegrass is 3 L ha^{-1}) however, plants at 85% of the sites tested were controlled at an application rate of 3 L ha^{-1}.

There were only 4 sites in total where control was achieved at all of the flupropanate application rates tested.

DISCUSSION

The confirmation of flupropanate resistance in serrated tussock confirmed some land managers' concerns about resistance within the weed populations that they were attempting to control, whilst for others it came as a surprise. Many of the land managers involved in the survey believed their poor weed control outcomes were a result of recent higher than average rainfall events, on poor spray application or both. However, by using the herbicide resistance testing process, variables affecting herbicide control outcomes in these weeds - such as rainfall, soil type, water quality, application rate and temperature - were all able to be controlled giving, clear indications about herbicide resistance.

It has been proposed that continual use of group 0 herbicides (such as flupropanate) for a fifteen-to-twenty-year period results in the development of resistance (McLaren et al. 2008) so with both serrated tussock and African lovegrass having a long historical presence and history of attempted control in the Monaro region, these results should not come as a surprise. NSW Agriculture records document serrated tussock herbicide control trials using flupropanate commencing in the late 1970s, so given the over forty years use of this herbicide in the region, the results found are well within McLaren et al. (2008) predictions.

Resistance testing of seed samples from both serrated tussock and African lovegrass sites identified a mixture of resistant, developing resistance and susceptible populations (Figure 1, Table 1). The herbicide susceptible sites were generally located in areas with less history of flupropanate usage, however sites where herbicide resistance was identified had a variety of weed control histories.

Label and permit rates for flupropanate use on serrated tussock in NSW are 1.5-2 L ha^{-1} and for African lovegrass 1.5-3 L ha^{-1} (APVMA PER9792). Lower rates of the herbicide are recommended for lighter soil types (granite and sedimentary type soils) and in situations where desirable species or only young weed seedlings are present. It is worth noting that for many of the sites where of resistance was confirmed or found to be developing, the rate of plant survival was much higher at low rates of herbicide application for both serrated tussock and African lovegrass. In most, but not all instances, increases in plant control were achieved when the application rate was increased (up to 3 L ha^{-1}). Whilst lower application rates are usually recommended to try and limit damage to desirable vegetation (usually valuable pasture species) surrounding the target weeds, these results are concerning and highlight the risk of more rapid selection for resistance in these weed populations when low rates of herbicide are applied without other management follow-up undertaken to remove surviving plants.

If low rates of flupropanate are continually used over large populations of perennial grass weeds without the follow-up control of surviving plants, we are likely to see a rapid increase of herbicide resistant populations. Ramasamy et al. (2010) found that serrated tussock plants primarily self-fertilised and that serrated tussock plants resistant to flupropanate would go on to produce at least 85–90 % herbicide resistant seeds. This rate of self-replication indicates that once a resistant population of serrated tussock has developed, it is likely to keep increasing in the absence of a change in control tactics. Possible dilution of the resistant gene pool by introducing susceptible plants is unlikely to yield significant changes in populations of herbicide controllable plants.

The rate of self-fertilisation of African lovegrass is unknown so the rate of resistance expansion within the population of this species cannot be discussed. It is also unknown if herbicide resistant populations of either serrated tussock or African lovegrass are less or more competitive in the environment. Early investigations into the fitness of herbicide resistance African lovegrass plants have commenced with no variation in germination rates recorded to date and other characteristics including the rate of photosynthesis, water-use efficiency, above and belowground rates of biomass production and plant reproduction rates still under investigation (J. Brown, personal communication, January 12, 2022).

Despite warnings from researchers who had identified three separate populations of flupropanate resistant serrated tussock back in the early 2000s, little has changed in the management of perennial grass weeds in pasture systems. This "head in the sand" approach to managing herbicide resistance in pasture systems has resulted in the development of resistance to a key herbicide used to control both serrated tussock and African lovegrass.

The confirmation of flupropanate resistance in serrated tussock (Powells 2018) and African lovegrass would not come as a surprise to those working in the field of weed ecology and the development of herbicide resistance. What is now needed is a focus on slowing down further development of herbicide resistance, thus allowing more time for additional chemistries to be identified (Gaines et al. 2021). A focused and more comprehensive approach to the application of integrated weed management principles is also required along with the consideration of any additional, new or novel control options for perennial grass weeds.

In the more challenging parts of the landscape, control of perennial grass weeds may never be cost-effective for an individual land manager and engaging with all types of land managers to prompt action regarding their responsibility for weed management remain a challenge at all levels. However, the true environmental cost of not taking action and allowing continued weed spread landscape degradation to occur cannot be overstated.

The results of these herbicide resistance studies have significant implications for how serrated tussock and African lovegrass are managed not only the Monaro, but also in other tablelands perennial pasture systems into the future. They reinforce the need for integrated approaches to be taken for the control of perennial grass weeds and the importance of herbicide resistance testing in pasture systems.

The confirmation of herbicide resistance in both serrated tussock and African lovegrass in perennial grass pastures indicates that not only is the "genie out of the bottle" as suggested by McLaren et al. (2010) but the widespread scale of the resistance across the Monaro, Southern Tablelands and more recently locations within the Central Tablelands of NSW (Upper Macquarie County Council 2022) suggests that the herbicide resistance ship has sailed, and the horse has truly bolted.

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