Science of the Total Environment 557–558 (2016) 773–784

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Effect of sugarcane cropping systems on herbicide losses in surface runoff

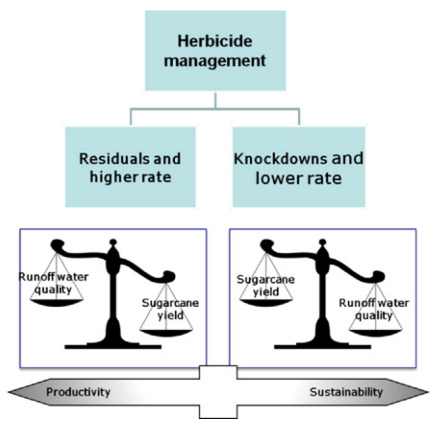
Gunasekhar Nachimuthu [a,b,*], Neil V. Halpin [b], Michael J. Bell [c]

[a] NSW Department of Primary Industries, Australian Cotton Research Institute, 21888 Kamilaroi Highway, Narrabri, NSW 2390, Australia
[b] Department of Agriculture and Fisheries (QLD), Bundaberg Research Facility, 49 Ashfield Road, Kalkie, QLD 4670, Australia
[c] School of Agriculture and Food Sciences, The University of Queensland, Gatton, QLD 4343, Australia

HIGHLIGHTS

- We evaluated four sugarcane cropping systems for herbicide loss in runoff
- Soil and trash management effects on herbicide losses were of primary importance
- The physico-chemical properties of herbicide on losses were less pronounced
- Improved practices reduced Atrazine losses by 62% relative to Conventional Practice

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 21 January 2016
Received in revised form 15 March 2016
Accepted 15 March 2016
Available online 17 April 2016

Editor: D. Barcelo

Keywords:
Atrazine
Diuron
Metolachlor
Pendimethalin
Metribuzin
Paddock to reef

ABSTRACT

Herbicide runoff from cropping fields has been identified as a threat to the Great Barrier Reef ecosystem. A field investigation was carried out to monitor the changes in runoff water quality resulting from four different sugarcane cropping systems that included different herbicides and contrasting tillage and trash management practices. These include (i) Conventional – Tillage (beds and inter-rows) with residual herbicides used; (ii) Improved – only the beds were tilled (zonal) with reduced residual herbicides used; (iii) Aspirational – minimum tillage (one pass of a single tine ripper before planting) with trash mulch, no residual herbicides and a legume intercrop after cane establishment; and (iv) New Farming System (NFS) – minimum tillage as in Aspirational practice with a grain legume rotation and a combination of residual and knockdown herbicides.

Results suggest soil and trash management had a larger effect on the herbicide losses in runoff than the physico-chemical properties of herbicides. Improved practices with 30% lower atrazine application rates than used in conventional systems produced reduced runoff volumes by 40% and atrazine loss by 62%. There were a 2-fold variation in atrazine and >10-fold variation in metribuzin loads in runoff water between reduced tillage systems differing in soil disturbance and surface residue cover from the previous rotation crops, despite the same herbicide application rates. The elevated risk of offsite losses from herbicides was illustrated by the high concentrations of diuron (14 μg L^{-1}) recorded in runoff that occurred >2.5 months after herbicide application in a 1st ratoon crop. A cropping system employing less persistent non-selective herbicides and an inter-row soybean mulch resulted in no residual herbicide contamination in runoff water, but recorded 12.3% lower yield compared

* Corresponding author at: NSW Department of Primary Industries, Australian Cotton Research Institute, 21888 Kamilaroi Highway, Narrabri, NSW 2390, Australia.
E-mail address: guna.nachimuthu@dpi.nsw.gov.au (G. Nachimuthu).

http://dx.doi.org/10.1016/j.scitotenv.2016.03.105

to Conventional practice. These findings reveal a trade-off between achieving good water quality with minimal herbicide contamination and maintaining farm profitability with good weed control.

1. Introduction

In Australia, sugarcane and grazing lands have been a major focus for export of nutrients, sediment and agricultural chemical residues from the Great Barrier Reef (GBR) catchments (Brodie et al., 2012; King et al., 2013; Masters et al., 2008; Masters et al., 2013; Mitchell et al., 2005; O'Reagain et al., 2005). The Burnett-Mary catchment discharges into the southern part of GBR lagoon. The main crops grown in this region include sugarcane, vegetables, tree crops for fruits and nuts and grain legumes. An initial investigation carried out in the Burnett-Mary Region (Stork et al., 2008b) identified the presence of nutrients and herbicides in runoff water from vegetable, macadamia and sugarcane production systems.

The sugar industry in the Burnett-Mary has a gross value of $196 M. The sugarcane crop is typically grown for four years, with one plant crop and three ratoon crops followed by a break crop (vegetables or grain legumes) or a bare fallow. Planting of sugarcane usually happens in spring (late Aug–Sept) or autumn (March–April). Several herbicides are applied to sugarcane, primarily from planting to just after fill-in (canopy closure), although occasionally herbicide sprays may occur at a later stage in weedy fields. Applications during the planting to fill-in period coincide with the summer rainfall season for the spring-planted crop, which represents the period of highest risk of losing herbicides in runoff. The sugarcane industry in Australia is currently developing an industry best management practices (BMP) to improve the sustainability of the cropping systems (Sugarcane BMP, 2015). Any additional information on improved herbicide management practices will lead to improvement in the Smartcane BMP program.

It has been clearly demonstrated that herbicides used on sugarcane farms, especially residual herbicides such as diuron, ametryn, atrazine and metribuzin, can move into waterways in runoff (Masters et al., 2013; Stork et al., 2008a; Stork et al., 2008b). Such herbicide contamination of waterways discharging into the GBR lagoon has been reported to impact on aquatic life in a number of studies (Jones, 2005; King et al., 2013; Råberg et al., 2003; Smith et al., 2012), so minimizing such losses through improved management practices (especially for residual herbicides, such as atrazine and diuron) has been a clear focus of research and best practice implementation programs.

The Australian Government has implemented the Reef Rescue program (Reef Rescue program, 2008) to help growers and managers improve farming practices in an attempt to improve water quality in the GBR lagoon by reducing the amount of nutrient, herbicides and sediment leaving farms in runoff. This program was based on the hypothesis that a reduction in pollutant loads could be directly correlated with the adoption of improved farming practices, although only a few studies have quantified this link. Most of the research that compares different herbicide management practices in northern Australia used small plot rainfall simulators to assess herbicide losses (Masters et al., 2013), with only limited field monitoring having been conducted (Oliver et al., 2014; Stork et al., 2008a). In some cases that monitoring was for a very limited duration (e.g. from a single irrigation event (Oliver et al., 2014)).

In addition to the shortage of seasonal or annual monitoring of farm scale herbicide losses from sugarcane cropping systems in GBR catchments, there are also few field programs (other than rainfall simulation studies) comparing grower standard practices with other management approaches. Given the general scarcity of field scale data on herbicide loss from irrigated sugarcane cropping systems, the ability to reliably predict the impact of changed management practices on water quality in GBR catchments is seriously limited.

Our study is one of the first of its kind for the sugarcane industry and is aimed at addressing this current knowledge gap. We have measured the herbicide concentrations and calculated loads leaving adjacent management strips in a cropping field. The concentrations of selected herbicides (diuron, atrazine, metribuzin, metolachlor and pendimethalin) in soil and trash were also quantified over time to assess herbicide persistence and risk of off-farm impacts in the longer term.

2. Materials and methods

A three-year field investigation was conducted to quantify the impact of different land management practices on offsite water quality generated during the fallow (vegetable or grain legume) and sugarcane production phases of regionally significant intensive cropping systems. The grain legume and intensive vegetable systems were assessed during a one-year rotation break, during which crops of soybean or sequential crops of capsicum and zucchini were grown, followed by a return to a sugarcane cycle monitored during the plant and subsequent 1^{st} ratoon crops. Management practices were assessed for their capacity to reduce sediment, nutrient and herbicide movement from fields to streams. This paper focuses on the herbicide data monitored during the sugarcane plant cane (2011 − 12) and first ratoon crop (2012 − 13) crops.

2.1. Site description

The site was established in the Burnett Mary region of Queensland, Australia, in a well-drained field containing a mixture of Yellow Brown Chromosol or Dermosol soils (Isbell, 2002) depending on location. The average sand, silt and clay fractions of the soil were 77%, 16% and 8%, respectively. The area has a subtropical climate where long term average mean maximum and minimum temperatures were 17 and 27 °C and the long-term average rainfall of 1019 mm sees >50% of rain fall in the summer months (Jan–Mar). Soil pH and organic carbon were 6.5 and 1%, respectively.

The site was a commercial cane field that was very uniform in the top 70 cm of the soil profile. The field was split into four management units with each unit being 280 m long and 9 m wide (i.e. 5 × 1.83 m cane rows), with contrasting management systems randomly allocated to each strip. The 280 m length was subdivided into two subunits of approximately 120 m and 160 m based on a highpoint in the middle of the field, with drainage in either direction in response to a 1% slope. Runoff flumes were installed to quantify the runoff, sediment and herbicide movement from the smaller 120 m × 9 m blocks (Fig. 1), while the 160 m × 9 m blocks were used for nutrient investigations (Nachimuthu et al., 2013).

The management systems and their various management practices are described in Table 1. Key features of these systems were as follows - (i) *Conventional practices* - current commercial practice consisting of full tillage after an intensive vegetable rotation and the application of traditional residual herbicides; (ii) *Improved practices* - only the beds were tilled after the vegetable phase (zonally tilled with the inter-space left undisturbed) and residual herbicide rates were reduced; (iii) *Aspirational practices* – a minimum tillage system (one pass of a single tine ripper in the bed zone prior to the vegetable and sugarcane phases), where vegetative trash mulch was maintained during cane planting, no residual herbicides were used and a legume intercrop was sown after cane establishment; and (iv) *New Farming System* (*NFS*) – a minimum tillage system (as in Aspirational practice) with grain legume rotation crops, retention of a surface trash mulch and a combination of residual and knockdown herbicides.