**Mass concentration and size distribution of particles released from harvesting and biomass burning of sugarcane**

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**Abstract**

We evaluated size distribution and mass concentrations of fine (particulate matter < 2.5 \(\mu\)m, PM\(_{2.5}\)) and coarse (particulate matter = 2.5–10 \(\mu\)m, PM\(_{2.5-10}\)) particles released during sugarcane (Saccharum spp.) harvesting operations, including cutting of green cane (GH), burning of standing cane (SB), cane harvest cutting after SB (BH), and ground burning of harvest residues left in the field (GB). Total number of PM\(_{2.5}\) released from GB was 1.63 times greater than that from SB. Total time of burning (flaming + smoldering) phase during GB was 1.5 to 2.1 times longer than SB. The flaming phase for both GB and SB was shorter than the smoldering phase but emitted 5.2 to 7.5 times more PM\(_{2.5}\). Average particle density of PM\(_{2.5}\) from burning operations was 1.12 g cm\(^{-3}\) for GB and 0.52 g cm\(^{-3}\) for SB. The GH and BH released lower PM\(_{2.5}\) but higher PM\(_{2.5-10}\) as compared to SB and GB. Overall, biomass burning, regardless GB and SB difference, released significantly higher PM\(_{2.5}\) than harvest-cutting operations.

**1 | INTRODUCTION**

Agricultural biomass burning contributes two-thirds of total primary organic aerosols in the atmosphere (Bond et al., 2013). These aerosols are capable of adsorbing and scattering sunlight, changing climatic conditions as they create cloud condensation nuclei, and reducing visibility. Finer fractions of particulate matter (PM) can also penetrate much deeper into human respiratory tract and are responsible for major health issues including chronic obstructive pulmonary disease, asthma, bronchitis, lung cancer, cardiac arrhythmia, or even heart attacks (Chen et al., 2013). This is an open access article under the terms of the Creative Commons Attribution License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited.

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et al., 2016; Xing, Xu, Shi, & Lian, 2016). Burning of crop residues is common in many parts of the world, although it has been increasingly prohibited and is a crop-specific practice in the United States (FAO, 2020; Yang et al., 2020).

Sugarcane (Saccharum spp.), a high biomass producing crop, is primarily produced in Louisiana and Florida, accounting for 96% of the total sugarcane production in the United States (USDA-ERS, 2020). Approximately 3.8–24.2 Mg ha\(^{-1}\) sugarcane harvest residues are generated annually (Judice, Griffin, Etheredge, & Jones, 2007;Viator, Johnson, Richard, Waguespack, & Jackson, 2008), and the harvest process involves residue burning either before or after harvest cutting. While burning leaves off before harvest cutting enhances sugarcane milling efficiency and increases sucrose content, ground burning of harvest residue can eliminate the low yield effect on ratoon sugarcane crops due to the thick groundcover of harvest trash, which is especially true under the subtropical climate in Louisiana (Viator, Johnson, Grimm, & Richard, 2006; 2009a). Although some farmers have developed physical sweeping implements to push harvest residue off the raised bed to avoid residue burning, it does not show much improvement in sugarcane yields (Viator, Johnson, & Richard, 2009b). In addition, recent studies showed that burning post-harvest sugarcane residue reduces ammonia and nitrous oxide emissions (Dattamudi, Wang, Dodla, Arceneaux, & Viator, 2016; 2019), controls weed density such as reducing emergence of itchgrass (Rottboellia cochinchinensis (Lour.) W.D. Claton) and divine nightshade (Solanum nigrescens M. Martens & Galeotti) (Spaunhorst, Orgeron, & White, 2019), and eliminates sugarcane borers and beetles (Legendre, 2001) compared with fields left unburned. However, there is no systematic study available addressing how these different harvest practices affect PM emissions.

Particle size is often used to characterize the behavior of PM in ambient air and its effects on atmospheric chemistry. Size distribution of particles released from a biomass burning event largely depends on biomass type, weather conditions, time and duration of sample collection, and other factors (Rajput, Sarin, Rengarajan, & Singh, 2011; Singh, Rajput, Sharma, Sarin, & Singh, 2014; Zhang, Wooster, Green, & Main, 2015). Size distribution and mass concentration of particles released from biomass burning in the laboratory settings are well documented (Hosseini et al., 2010; Park, Sim, Bae, & Schauer, 2013; Zhang et al., 2011). However, research studies on concentration and size profiling of particles in source regions are limited, specifically for different agricultural harvesting operations. Therefore, this multiple-year field study was planned to evaluate the mass and size distributions of particles emitted during different sugarcane harvesting operations in Louisiana.

### Core Ideas
- Burning events emitted primarily PM\(_{2.5}\), whereas harvest cutting released mainly PM\(_{2.5-10}\).
- Ground burning harvest residue emitted more but heavier density PM\(_{2.5}\) than stand burning cane.
- Shorter flaming phase released more PM\(_{2.5}\) than longer smoldering phase.
- The more complete the cane biomass burn, the lighter particulate matter density produced.
- Both ground and stand burn practices pose potential air quality risk despite varying PM release.

## MATERIALS AND METHODS

### 2.1 Sampling sites and harvesting operations

Sugarcane fields at Louisiana State University AgCenter research stations in New Iberia and St. Gabriel, LA, were used for this study during 2012–2014. Samples were collected during four sugarcane harvesting events, including regular harvesting of green cane without any burn, or green cane harvesting (GH); burning of standing cane leaves before harvesting, or standing burn (SB); harvesting of cane after standing burn, or burned cane harvesting (BH); and burning of post-harvest residues, or ground burn (GB). While SB is generally followed by combine harvesting, GH could be a lone operation or followed by GB operation if burning the residue is so desired before ratoon cane growth season begins. The GB events were generally conducted 5–10 d after GH depending on the moisture conditions of the field and residue. Sample collections for either harvesting or burning operations were performed between 11:00 a.m. and 2:00 p.m. during the day. All sample collections were carried out when fields were dry and under relatively the same weather conditions. Average wind speed, air temperature, and relative humidity during sample collections were 6.3 ± 0.7 km h\(^{-1}\), 13.7 ± 1.9 °C, and 57 ± 6%, respectively. Total numbers of sample collections for GH, BH, SB, and GB were 20, 18, 18, and 22, respectively, over 3 yr.

### 2.2 Sample collection and analysis

Size distribution of total suspended particulates was recorded using a Met One optical particle 212 profiler (Met
One Instruments Inc.). The profiler (3 m above the soil surface) was in downwind position and maintained at about 15 m away from the field during each harvest event and operated at 1 L min$^{-1}$. The profiler was turned on about 15–20 min before the actual harvesting or burning to establish particle concentrations in the ambient air (background concentration) and run for additional 15–20 min after the burning or combine was complete. The burning was divided into flaming phase and smoldering phase based on visual observations with approximately overlapping of the two phases less than 15% of overall burning time. It was so set since the exact separation of the two burning phases was practically impossible particularly under the field situation.

Particles released during harvesting and burning events were also collected on quartz microfiber filters (Whatman International Ltd.) using a Tisch TE-6070 high volume air sampler (Tisch Environmental Inc.) at downwind position (1.8 m above the ground) about 6 m away from field edge and operated at a flow rate of 40 ft$^3$ min$^{-1}$ (1,133 L min$^{-1}$). The high volume air sampler was positioned at the same distance for all the collection events to reduce variability between various sampling events. The mass concentration of PM$_{2.5}$ (<2.5 μm) was determined by measuring the filter weight before and after sample collection (USEPA, 2017). Statistical analyses were performed using SAS 9.4 (SAS Institute, 2013) for analysis of variance (ANOVA) and mean separation was by Tukey-Kramer at $\alpha = .05$ level.

3 | RESULTS AND DISCUSSION

3.1 | Size distribution of particles

Total numbers of fine particles (PM$_{2.5}$) released during GB and SB operations were $(4.15 \pm 0.54) \times 10^7$ and $(2.54 \pm 0.49) \times 10^7$, respectively, indicating 60–65% higher PM$_{2.5}$ from GB than from SB (Figure 1). The duration of burning period for GB was about 1.5 to 2.1 times longer than SB operation. The longer period of GB could be due to the reduced or incomplete burning phase for residues left in the field ground as a trash blanket (Hosseini et al., 2010; Zhang et al., 2015), and the incomplete combustion was known to release higher PM$_{2.5}$ to the air (Johansson, Tullin, Leckner, & Sjövall, 2003; Tissari, 2008). Visual observations suggest that the flaming phase was generally quicker than the smoldering phase for both GB and SB.
operations, but the flaming phase released about 5.2 to 7.5 times higher PM$_{2.5}$ than smoldering phase. According to Akagi et al. (2011), the flaming phase of biomass burning can often reach temperatures more than 1,000 °C and plays a vital role in releasing finer carbonaceous particles. On the other hand, smoldering combustion, which includes surface oxidation (gasification) and pyrolysis, mainly produces CO, CH$_4$, primary organic aerosols, and volatile organic compounds. In this study, the average number of PM$_{2.5}$ released per minute in GB was significantly higher ($P < .05$) than SB during the smoldering phase of biomass burning. The number of coarse particles (PM$_{2.5-10}$) released from both GB and SB was almost negligible compared with PM$_{2.5}$. Nonetheless, SB operation showed significantly higher PM$_{2.5-10}$ than GB, opposite from the PM$_{2.5}$ emission (Figure 1). Total PM$_{2.5}$ released from BH and GH events were $(3.9 \pm 0.62) \times 10^6$, and $(3.1 \pm 0.47) \times 10^6$, respectively, with the former being about 24–28% higher than the latter (Figure 2). Note that some of the total PM$_{2.5}$ released during both BH and GH was possibly from soil dust produced during harvest-cutting operation with a harvester. However, PM$_{2.5-10}$ released from GH was 60% higher (significant at $P < .05$) than BH. In addition, both GH and BH released significantly higher coarse particles than GB and SB, emphasizing the high amount of plant particles released during cutting the cane.

Overall, multimodal distributions of particles were observed for both burning phases, especially in the later stage of smoldering, possibly resulting from the nucleation and condensation of released volatile compounds when the temperature of smoking went down (Hosseini et al., 2010; Rastogi, Singh, Singh, & Sarin, 2014). In addition, multiple peaks of PM emission for GH and BH were due to the change of distance between the optical profiler and the harvester during the combine process.
### TABLE 1
Concentration (μg m⁻³) of fine particles (particulate matter <2.5 μm, PM₂.₅) during different harvesting operations of sugarcane in Louisiana

| Harvesting operation                  | PM₂.₅ concentration μg m⁻³ | Mass of single particle × 10⁻³ ng |
|---------------------------------------|----------------------------|----------------------------------|
| Green cane harvesting (GH)            | 839 ± 193 a                | 8.40 ± 1.57 a                    |
| Harvesting after SB (BH)              | 1,050 ± 250 a              | 7.80 ± 1.82 a                    |
| Ground burn (GB)                      | 3,433 ± 313 b              | 4.71 ± 0.62 b                    |
| Standing burn (SB)                    | 1771 ± 154 c               | 2.15 ± 0.53 c                    |

Note. Data presented (mean ± SD) are an average of samples collected over 3 yr. Different lowercase letters in the table represent statistically significant at α = .05 level.

* Concentration of source region during harvesting and burning operations.

#### 3.2 Mass concentration of particles

The average mass concentration of PM₂.₅ in GB samples was significantly higher than SB (Table 1), consistent with the trend of total numbers of PM₂.₅ emission (Figure 1). Average mass concentrations of PM₂.₅ emitted from GH and BH were significantly lower than GB and SB. The average PM₂.₅ mass concentration of 3,433 ± 313 μg m⁻³ from GB operation was comparable to that of 4,000 ± 2,000 μg m⁻³ reported for source region of ground burning of wheat (*Triticum aestivum* L.) stubble spreading (Zhang et al., 2015). Based on total numbers of particles collected from the optical profiler and mass concentration from quartz microfiber filters during the same period, the average mass of single PM₂.₅ particle from GB and SB was estimated at (4.71 ± 0.62)×10⁻³ ng and (2.15 ± 0.53)×10⁻³ ng, respectively. This would amount to 1.13 and 0.52 g cm⁻³ of particle density (assuming all spherical particles) of PM₂.₅ released from GB and SB, respectively. These results were lower than 1.50–1.53 g cm⁻³ of PM₂.₅ found in ambient air in a study showing secondary aerosols formed from high sulfate concentrations (Tuch et al., 2000). On the other hand, the particle density of PM₂.₅ from GH and BH operations was calculated to be 2.00 and 1.88 g cm⁻³, respectively, much greater than those from GB and SB. These results suggest more complete burning of harvest biomass than that from GB, likely posing greater air quality risks even though its emitted total number of PM₂.₅ particles was less compared with GB operation. Smoke and black particles from SB were visibly flying higher vertically compared with GB particles during burning events.

#### 4 CONCLUSION

Biomass burning is an important residue management practice in subtropical sugarcane production as it increases the yield of the subsequent ratoon crop and enhances milling efficiency. In this study, we evaluated the effect of harvesting and burning events on mass concentrations and size distributions of released particles. For both GH and BH operations, these events tend to generate smaller numbers of total PM₂.₅ but higher PM₂.₅-10⁻³, which travels only a short distance. For biomass burning, the SB operation released lower total numbers of PM₂.₅ particles per event with lighter density, whereas GB emitted greater but slightly heavier fine particles. These results suggest different agronomic and environmental implications for sugarcane harvesting and biomass burning operations. While the GH process generally releases the least number of fine particles with low health risks and harvest residue retention followed could reduce soil erosion and increase soil organic matter, it leads to decreased yields due to high harvest residue in the field that could impede herbicide application, fertilization, and rebuilding of the row profile for spring cultivation of ratoon cane. On the other hand, burning of harvest residue has benefits of reducing ammonia loss and nitrous oxide emission as well as improving weed control in the ratoon cane crop. Therefore, we must consider both positive and negative aspects of these field practices. Nonetheless, regardless of the difference between GB and SB, sugarcane biomass burning poses greater air quality and health risks with greater emission of fine particles than does the GH operation and needs to be carefully prescribed for field management.

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#### CONFLICT OF INTEREST

The authors declare no conflict of interest.

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REFERENCES

Akagit,S.K.,Yokelson,R.J.,Wiedinmyer,C.,Alvarado,M.,Reid,J.S.,
Karl,T.,...Wennerg,P.O.(2011).Emissionfactorsofopenand
domesticbiomassburningforuseinatmosphericmodels.
AtmosphericChemistryandPhysics,11(9),4039.

Bond,T.C.,Doherty,S.J.,Fahey,D.W.,Forster,P.M.,Berntsen,T.,
DeAngelo,B.J.,...Zender,C.S.(2013).Boundingtheroleofblack
carbonintheclimatesystem:Ascientificassessment.
JournalofGeophysicalResearch:Atmospheres,118(11),5380–5552.

Chen,R.,Hu,B.,Liu,Y.,Xu,J.,Yang,G.,Xu,D.,&Chen,C.(2016).
BeyondPM2.5:Theroleofultrafineparticlesonadversehealth
effectsofairpollution.
BiochimicaetBiophysicaActa-GeneralSubjects,1860(12),2844–2855.

Dattamudi,S.,Wang,J.J.,Dodla,S.K.,Arceneaux,A.,&Viator,H.
P.(2016).Effectofnitrogenfertilizationandresiduemangement
practicesonammoniaemissionsfromsubtropicalsugarcane
production.
AtmosphericEnvironment,139,122–130.

Dattamudi,S.,Wang,J.J.,Dodla,S.K.,Viator,H.P.,DeLaune,R.,His-
cox,A.,...Colyer,P.(2019).Greenhousegasemissionsasinflu-
enced by nitrogen fertilization and harvest residue management
in sugarcane production.
Agroecosystems,Geosciences&Environment,
2(1),190014.https://doi.org/10.2134/age2019.03.0014

FAO.(2020).Burning—Cropresidues.Retrievedfromhttp://www.
faostat.en/#data/GB

Hosseini,S.,Qi,L.,Cocker,D.,Weise,D.,Miller,A.,Shrivastava,M.,
...Jung,H.(2010).Particlesizedistributionsfromlaboratory-scale
biomassfiresusingfastresponseinstruments.
AtmosphericChem-
istryandPhysics,10,8065–8076.

Johansson,L.S.,Tullin,C.,Leckner,B.,&Sjövall,P.(2003).Particle
emissionsfrombiomasscombustionsmallcombustors.
Biomass
andBioenergy,25(4),435–446.

Judice,W.E.,Griffin,J.L.,Etheredge,Jr.,L.M.,&Jones,C.A.(2007).
Effects of crop residue management and tillage on weed control
and sugarcane production.
WeedTechnology,21,606–611.

Legendre,B.L.(2001).Prescribedburnshelpthesugarcaneindustry
andreduce smokemashproblems.
LouisianaAgriculture,44(4),
36–37.

Park,S.S.,Sim,S.Y.,Bae,M.S.,&Schauer,J.J.(2013).Sizedistribu-
tionofwater-solublecomponentsinparticulatematteremitted
from biomass burning.
AtmosphericEnvironment,73,62–72.

Rajput,P.,Sarin,M.M.,Rengarajan,R.,&Singh,D.(2011).Atmo-
spheric polycyclic aromatic hydrocarbons (PAHs) from post-
harvest biomass burning emissions in the Indo-Gangetic Plain:
Isomer ratios and temporal trends.
AtmosphericEnvironment,
45(37),6732–6740.

Rastogi,N.,Singh,A.,Singh,D.,&Sarin,M.M.(2014).Chemical
characteristics of PM2.5 at a source region of biomass burning emis-
sions: Evidence for secondary aerosol formation.
EnvironmentalPollution,184,563–569.

SASInstitute.(2013).SAS9.4statements:Reference.Cary,NC:SAS
Institute.

Singh,A.,Rajput,P.,Sharma,D.,Sarin,M.M.,&Singh,D.(2014).
Black carbon and elemental carbon from postharvest agricultur-
waste burning emissions in the Indo-Gangetic Plain.
AdvancesinMeteorology,2014,179301.

Spaunhorst,D.J.,Orgeron,A.J.,&White,Jr.,P.M.(2019).Burn-
ingpostharvestsugarcane residue forcontrol of surface-deposited
divinenuightshade (Solanum nigrrescens) and itchgrass (Rothoella
cochinchinensis)seed.
WeedTechnology,33(5),693–700.

Tissari,J.(2008).Fine particle emissions from residential wood com-
bustion.
Kuopio,Finland:UniversityofKuopio.

Tuch,T.,Mirme,A.,Tamm,E.,Heinrich,J.,Heyder,J.,Brand,P.,
...Kreyling,W.G.(2000).Comparisonoftwo particle-size spec-
trometersforambientaerosolmeasurements.
AtmosphericEnvi-
ronment,34(1),139–149.

USDA-ERS.(2020).Sugarandsweetenersoutlook.Retrievedfrom
https://www.ers.usda.gov/webdocs/outlooks/98658/sss-m-
382.pdf?v=6369.4

USEPA.(2017).Manual reference method: RFPS-0202-141.
Retrievedfrom
https://www3.epa.gov/ttnamti1/files/ambient/criteria/
AMTIC_List_June_2017_update_6-19-2017.pdf

Viator, R. P., Flanagan, J., Gaston, L., Hall, S., Hoy, J., Hymel, T., ... Zhou, M. (2009a). The influence of post-harvest residue manage-
ment on water quality and sugarcane yield in Louisiana.
Journal of theAmericanSocietyofSugarCaneTechnologists,29,1–10.

Viator,R.P.,Johnson,R.M.,Grimm,C.C.,&Richard,Er.P.(2006).
Allelopathic,autotoxic,andhormeticeffectsofpostharvestsugarcane
residue.
AgronomyJournal,98,1526–1531.

Viator, R. P., Johnson, R. M., & Richard, Jr, E. P. (2009b). Effects of
mechanicalremovalandincorporationofpost-harvestresidueon
ratosonsugarcaneyields.
SugarCaneInternational,24(4),149–152.

Viator,R.P.,Johnson,R.M.,Richard,E.P.,Waguespack,H.L.,
&Jackson,W.(2008).Influenceofnonoptimalripenerapplications
and postharvest residue retention on sugarcane second ratoon
yields.
AgronomyJournal,100(6),1769–1773.

Xing,Y.F.,Xu,Y.H.,Shi,M.H.,&Lian,Y.X.(2016).Theimpactof
PM2.5onthehumanrespiratorysystem.
JournalofThoracicDisease,
8(1),E69.

Yang,G.,Zhao,H.,Tong,D.Q.,Xiu,D.,Zhang,X.,&Gao,C.(2020).
Impacts of post-harvest open biomass burning and burning ban
policyonseverehazeintheNortheasternChina.
ScienceoftheTotalEnvironment,716,136517.

Zhang,H.,Hu,D.,Chen,J.,Ye,X.,Wang,S.X.,Hao,J.M.,...An,Z.
(2011).Particle size distribution and polycyclic aromatic hydrocar-
bonsemissionsfromagriculturercropresidueburning.
Environmental
Science & Technology,45(13),5477–5482.

Zhang,T.,Wooster,M.J.,Green,D.C.,&Main,B.(2015).Newfield-
basedagriculturalbiomassburningtracegasm,PM2.5,andalbedo-
carbonemissionratiofreassembledinthesitucropresidue
firesinneasternChina.
AtmosphericEnvironment,121,22–34.

Howtocitethisarticle:DattamudiS,WangJJ,
DodlaSK,etal.Massconcentrationandsizedistributionofparticlesreleasedfromharvesting
andbiomassburningsugarcane.
AgricEnvironLett.2020;5:e20028.
https://doi.org/10.1002/ael2.20028