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Evaluating the Effects of Early Pruning, Leaf Removal, and Shoot Thinning on 'MidSouth' Grapes over Two Consecutive Vintages in South Mississippi

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Abstract: Yield components and fruit composition of 'MidSouth', an interspecific hybrid bunch grape (*Vitis* spp.) with relatively low total soluble solids and high titratable acidity, was evaluated in south Mississippi to determine if treatments consisting of early pruning, early pruning with pre-bloom leaf removal, normal pruning with post-fruit set leaf removal, or normal pruning in one study, or post-fruit set leaf removal, post-fruit set shoot thinning, or neither leaf removal nor shoot thinning in a second study could improve these qualities. Early pruning with leaf removal reduced berries per cluster, cluster weights, yields, and Ravaz index. Early pruning treatments had inconsistent results from year to year, and normal pruning treatments were not often significantly different. Shoot thinned vines had lower yields and Ravaz index and higher total soluble solids. Second study leaf removal vines had lower juice pH in 2020 and lower yield per vine in 2021. These findings show that 'MidSouth' can be altered by these practices, but they did not appear to sufficiently alter 'MidSouth' quality. Thus, early pruning with or without leaf removal, normal pruning with leaf removal, and shoot thinning are not recommended for 'MidSouth' in south Mississippi, and normal pruning without these practices should be continued.

Keywords: canopy management; grape composition; grape ripening; humid environment; interspecific hybrid; red wine

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Citation: Williams, H.N.; Stafne, E.T.; Zhang, Y.; Chang, S.K.C. Evaluating the Effects of Early Pruning, Leaf Removal, and Shoot Thinning on 'MidSouth' Grapes over Two Consecutive Vintages in South Mississippi. *Agronomy* **2023**, *13*, 368. https://doi.org/10.3390/agronomy13020368

Academic Editors: Massimo Bertamini and Michele Faralli

Received: 29 December 2022
Revised: 23 January 2023
Accepted: 24 January 2023
Published: 27 January 2023

1. Introduction

Despite efforts to develop bunch grape (*Vitis* spp.) cultivars from other regions and develop new cultivars, there are few bunch grapes that are well-suited for growth in Mississippi [1]. The state has a subtropical climate, where temperature, humidity, and rainfall remain relatively high the entire year, especially in south Mississippi [1–3]. The warm temperatures and long ripening season allow grapes to properly ripen, but the high humidity and high temperatures at night generate other problems, such as disease and increased dark respiration, which utilizes sugars and limits their accumulation [1,4].

A relatively low maintenance interspecific hybrid, dark blue-purple bunch grape that is currently grown in south Mississippi and surrounding states for its jelly and home garden use is 'MidSouth', which has *V. champinii* Planch., *V. vinifera* L., *V. rupestris* Scheele, *V. berlandieri* Planch., *V. lincecumii* syn. *V. aestivalis* var. *lincecumii* Buckley, and *V. labrusca* L. in its lineage. While it has comparatively low total soluble solids (TSS) and high titratable acidity (TA) for varietal red wine production, there has been a growing interest in the grape for wine use [5–7]. The TSS and TA for 'MidSouth' tend to range < 20 Brix and >10 g/L [7], respectively; however, the typical ranges for a dry red wine are a TSS range of 22 to 27 Brix and a TA range of 6 to 7 g/L [8]. Chaptalization and/or potassium bicarbonate additives could adjust these values in the winemaking process [9], but it is possible that early pruning, cluster zone leaf removal, and/or shoot thinning could alter these fruit qualities into a more acceptable range before they are harvested. However, results may vary depending on the location and cultivar, and the phenological stage at which these canopy management practices are performed [10–26].

The timing of phenological events of vines, such as budburst, flowering, veraison, and shoot growth are affected by the timing of pruning [1,10,11]. Pruning of 'MidSouth' is typically performed in late February or early March in south Mississippi while vines are still dormant, but this results in a harvest time that is hot and humid and unfavorable for both the grapes and harvesters. Pruning at this time allows for a delay in growth and avoidance of frosts in the late winter and early spring [1]; however, examinations of 'MidSouth' after exposure to frost suggest that it is at least somewhat cold hardy and could endure cold winter temperatures [7,27]. If pruning earlier resulted in a hastened growth cycle, this could lead to an earlier harvest that would be more tolerable for both the fruit and harvesters and could yield 'MidSouth' fruit with qualities more suitable for wine production.

If applied early in a vine's growth cycle, leaf removal can result in limited sugar availability to aid in the flowering process, and this can quickly result in abscised flowers, which leads to a reduction in fruit set and crop yield [12]. In addition to this reduction, reduced cluster compactness can lead to a decrease in bunch rot incidence and severity [12,24]. This treatment also affects the photosynthetic processes of the vine. When too many leaves are on a vine, some leaves that are covered by others are not able to photosynthesize at their full capacity [28]. Thus, vines that are at least partially defoliated can have higher photosynthetic rates than non-defoliated vines because of more light and space availability for the leaves [13,29,30]. This can result in higher TSS, since sugar is accumulated during photosynthesis [12,14–16]. Reductions in TA have been reported as well, which could be attributed to increased cluster temperatures in exposed grapes leading to temperature-driven malic acid respiration [14,17–21]. While a costly reduction in crop yield has been seen with pre-bloom leaf removal [19], it has been reported that similar fruit quality and composition (i.e., reduced disease, higher TSS, and lower TA) can be achieved without yield reduction if leaf removal occurs after fruit set [19–24].

Shoot thinning is another practice that has been used to reduce yield and increase canopy openness to improve fruit quality [13]. When primary shoots are removed, the amounts of both vegetative and fruit sinks where assimilates and reserves are stored is reduced, and thus, there is an improved distribution of these reserves to the remaining vegetative and fruit sinks [25]. Cluster number and overall yield may be reduced, but the fruit of cluster thinned vines tend to have higher TSS and lower TA and disease [13,15,17,22,23,25,26].

The purpose of this study was to investigate pruning timing, leaf removal, and shoot thinning treatments and their effect on 'MidSouth' grapevine phenology, physiology, and resulting fruit quality to determine if 'MidSouth' has potential for varietal red wine production in south Mississippi.

2. Materials and Methods

Two experiments were conducted at the Mississippi Agricultural and Forestry Experiment Station (MAFES) McNeill Research Unit in McNeill, MS (30°64′ N, 89°62′ W; elevation 22 m asl; USDA hardiness zone 8b), where there is a humid and subtropical climate (Köppen climate Cfa) and sandy loam soil. A single row of seven-year-old 'MidSouth' vines runs for 300 m and is oriented north to south, and nearby rows of muscadine (*V. rotundifolia*) are at least 12.9 m away. All vines are trained to a high wire bilateral cordon system without irrigation. The 48 vines of the first study were spaced 4.3 by 2.7 m apart. Four different treatments were randomly assigned to vines within blocks to create a randomized complete block design of four blocks with three subsamples of each treatment within each block. Twelve vines received an early pruning treatment (treatment (T) 1.1), twelve received an early pruning plus leaf removal treatment (T1.2), twelve received a normal pruning plus leaf removal treatment (T1.3), and twelve received normal pruning as a control (T1.4). The

60 vines of the second study were spaced 4.3 by 1.5 m apart. Three different treatments were randomly assigned to vines within blocks to create a randomized complete block design of four blocks with five subsamples of each treatment within each block. Of these vines, 20 received a leaf removal treatment (T2.1), 20 received a shoot thinning treatment (T2.2), and 20 were controls that did not receive leaf removal or shoot thinning (T2.3).

Early pruning (T1.1, T1.2) took place on 16 Dec in 2019 and 15 Dec in 2020, and normal pruning (T1.3, T1.4, T2.1, T2.2, T2.3) took place from 29 Feb to 6 Mar in 2020 and from 28 Feb to 3 Mar in 2021. All vines were spur pruned to roughly 60 buds (Figure 1) based on previous studies in south Mississippi [31,32], and cuttings were weighed for later calculation of the Ravaz index (kg/kg), which is the yield to pruning weight ratio of a vine. The typical Ravaz index range for a well-balanced vine is five to ten, with those under this range considered under-cropped and those over considered over-cropped [33]. For leaf removal of early pruned vines (T1.2), three to six leaves were manually removed from the cluster zone of each primary shoot with a pre-bloom cluster (stage 18) [12,14,24,34]. For leaf removal of normal pruned vines (T1.3, T2.1), three to six leaves were removed from the cluster zone of each shoot with a fruit set cluster (stage 29) (Figure 2) [19–21,24,34]. For shoot thinning (T2.2), vines were thinned to approximately 15 primary shoots per meter of cordon [13,26] (Figure 3) at the post fruit set stage (stage 29) [34]. Phenological stages of the vines are based on the modified Eichhorn-Lorenz system [34].

Figure 1. 'MidSouth' grapevine before (**left**) and after (**right**) spur pruning to 60 buds in McNeill, MS (February 2021).

Figure 2. 'MidSouth' grapevine before (**left**) and after (**right**) cluster zone leaf removal of 3 to 6 leaves in McNeill, MS (May 2021).

Figure 3. 'MidSouth' grapevine before (**left**) and after (**right**) shoot thinning to 15 primary shoots per meter in McNeill, MS (May 2021).

The vines were sprayed with fungicide, alternating between Rally (active ingredient (a.i.): myclobutanil, Dow AgroSciences, Indianapolis, IN) at a rate of 0.29 L (0.12 L a.i.) per ha and Manzate Pro-Stick (a.i.: mancozeb, United Phosphorous Inc, King of Prussia, PA) at a rate of 3.08 kg (2.31 kg a.i.) per ha, beginning in late March and every two weeks until just before veraison (stage 35) [34] (early June) for fungal disease management of anthracnose (*Elsinoe ampelina* (de Bary) Shear) and black rot (*Phyllosticta ampelicida* (Engelm.) Aa) [31,35]. Finale (a.i.: glufosinate, BASF Corp, Research Triangle Park, NC) herbicide was applied at a rate of 9.35 L (1.06 kg a.i.) per ha two times in the season for weed control, and granular 13-13-13 fertilizer (N-P-K, Agri-AFC LLC, Decatur, AL) was applied by hand at a rate of 0.4 kg per vine in two applications: once in late March and again in early June [31,36].

In both studies, from veraison until harvest, weekly TSS, TA (primarily tartaric acid), and juice pH values were based on hand-picked samples of 20 berries per vine and determined using a Pocket Brix-Acidity Meter (PAL-BX | ACID 2, Atago Co. Ltd., Tokyo, Japan) and titration with a NaOH solution using an automatic mini titrator (HI84502U-01, Hanna Instruments, Woonsocket, RI). All vines were hedged to 0.3 to 0.6 m above the top wire before harvest to remove excess vegetative growth and detangle shoots for an easier harvest.

Daily temperatures were collected to calculate the number of growing degree days (GDD) throughout the growing season in each year. The equation for calculating GDD was daily maximum temperature + minimum temperature/2–base temperature, with the base temperature set at 10 °C.

To limit the loss of yields, the timing of grape harvest was determined when grapes began falling from the vines. This occurred in late July (30 July 2020 and 30 July 2021) for early pruned vines (T1.1, T1.2) and in early to mid-August (13 August 2020 and 4 August 2021) for normal pruned vines (T1.3, T1.4, T2.1, T2.2, T2.3). Grapes from each vine were collected and weighed separately to determine cluster weights and total yield per vine and later calculate yield per hectare and Ravaz index, and 20 berry samples were collected after weighing to determine average berry weight, berries per cluster, TSS, TA, and juice pH.

Data from each study were analyzed by analysis of variance using the general linear model in SAS statistical software (ver. 9.4; SAS Institute, Cary, NC). Means were separated using Tukey's studentized range (Honestly Significant Difference) test at $\alpha \leq 0.05$. Pairwise correlation of TSS and TA was tested by Pearson's correlation coefficient, also in SAS statistical software.

3. Results

3.1. Study 1

Normal pruning treatments (T1.3, T1.4) resulted in a normal harvest time of early to mid-August (Table 1). While pruned 2 months earlier, early pruning treatments (T1.1, T1.2) resulted in only a two-week earlier harvest in 2020 and a one-week earlier harvest in 2021, which fell in late July when conditions are still rather hot and humid (Table 1).

TSS and TA weekly measurements (Figure 4) displayed some fluctuation over the GDD. However, a strong negative correlation between the two variables ($p < 0.0001$, r = −0.70 (2020) and −0.84 (2021)) shows that as TSS increases, TA decreases. In both years, there was one week during the ripening period when there was an increase in TA following a decrease. This increase was between 1758 and 1871 GDD in 2020 and between 1710 and 1814 GDD in 2021 (Figure 4). Both increases followed high amounts of rainfall (>11.1 cm) in the previous week (Table 1). In both years, the TSS increased in the beginning of the ripening period, but the rate of increase slowed down and plateaued before harvest (Figure 4).

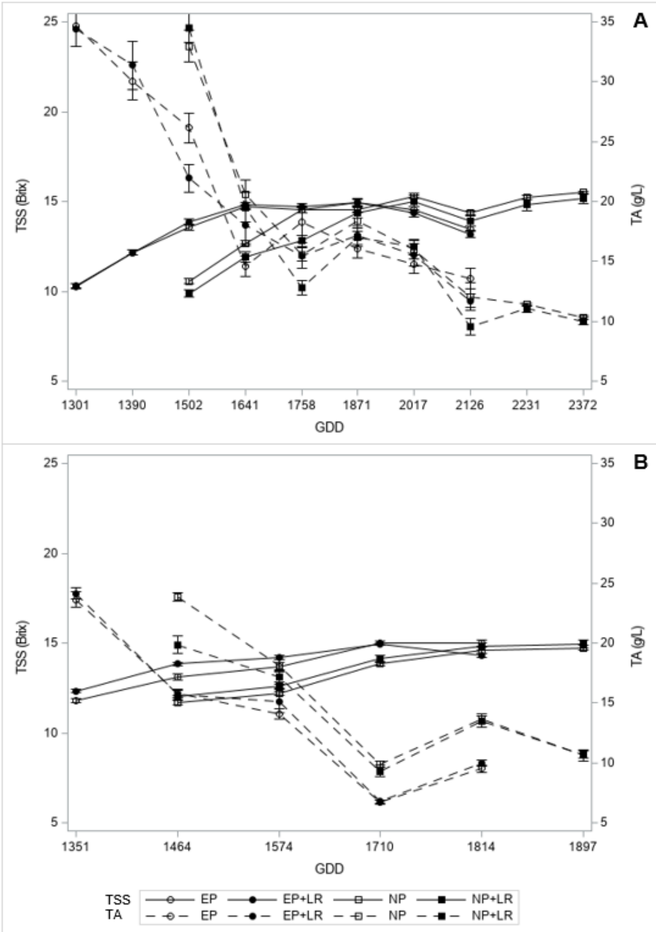

Figure 4. Weekly average 'MidSouth' total soluble solids (TSS) and titratable acidity (TA) for each treatment in Study 1 from veraison to harvest in 2020 (**A**) and 2021 (**B**) in McNeill, MS. EP, early pruning; EP + LR, early pruning + leaf removal; NP + LR, normal pruning + leaf removal; NP, normal pruning (control).

Table 1. Weekly phenological stage, rainfall, and average temperature and humidity near McNeill, MS starting from 'MidSouth' veraison to harvest for vines spaced 4.3 × 2.7 m in Study 1 (2020 and 2021).

2020						2021					
Week	**Phenological Stage of Early Pruned Vines** [a]	**Phenological Stage of Normal Pruned Vines** [a]	**Temperature (°C)** [b]	**Humidity (%)** [c]	**Rainfall (cm)** [b]	**Week**	**Phenological Stage of Early Pruned Vines**	**Phenological Stage of Normal Pruned Vines**	**Temperature (°C)**	**Humidity (%)**	**Rainfall (cm)**
1–16 June	35		25.2	61.4	3.0						
16–23 June			25.8	65.7	0.1						
23 June–1 July	36	35	27.1	79.4	4.6						
1–8 July			27.1	83.3	11.8	29 June-7 July	35		24.0	80.5	2.5
8–14 July	37	36	28.4	70.1	3.6	7–14 July	36	35	25.7	81.8	7.4
14–22 July			28.4	72.8	4.8	14–22 July	37	36	27.0	79.1	11.1
22–29 July	38	37	26.1	87.2	7.5	22–29 July	38	37	25.1	75.7	5.2
29 July-4 August			27.4	74.0	1.7	29 July–3 August		38	26.2	81.9	3.7
4–12 August		38	27.5	69.0	0						

[a] Stages adapted from modified Eichhorn-Lorenz system. [b] Data averaged from daily local measurements from Poplarville, MS (15 miles northeast of McNeill, MS). [c] Data averaged from daily local measurements fromStennis International Airport (33 miles southeast of McNeill, MS).

The measured variables that differed by both treatment and vintage include berry weight, yield per vine, TSS, TA, and juice pH (Table 2). In 2020, normal pruned vines with leaf removal (T1.3) had a lower berry weight compared with normal pruned vines without leaf removal (T1.4), but in 2021, both early pruning (T1.1, T1.2) treatments had lower berry weights. In 2020, early pruned vines with leaf removal (T1.2) had the lowest yield per vine, which did not significantly differ from early pruned vines without leaf removal (T1.1), and normal pruned vines (T1.3. T1.4) did not significantly differ from one another. In 2021, both early pruned vines (T1.1, T1.2) and normal pruned with leaf removal vines (T1.3) had lower yields per vine than normal pruned without leaf removal vines (T1.4). TSS was lower for both early pruning (T1.1, T1.2) treatments in 2020, but there were no significant differences between treatments in 2021. Early pruning with and without leaf removal (T1.1, T1.2) had the highest TA in 2020 but were not significantly different from others (T1.3, T1.4) in 2021. Juice pH was stable within each vintage, with higher values in 2021 (Table 2).

Table 2. 'MidSouth' mean ± standard deviation yield components and grape composition for each treatment, vintage, and treatment and vintage interaction in Study 1 in McNeill, MS (2020 and 2021).

Treatment (T) [a]	Berries per Cluster	Berry wt. (g)	Cluster wt. (g)	Yield (kg/vine)	Yield (kg/ha)	Ravaz Index (kg/kg)	TSS [b] (Brix)	TA [c] (g/L)	Juice pH
					2020				
1.1	14 ± 4 b [d]	3.21 ± 0.16 a	44.55 ± 15.10	2.65 ± 1.30 bc	2441.15 ± 981.34 ab	. [e]	13.48 ± 0.46 b	13.58 ± 3.01 a	3.31 ± 0.09
1.2	14 ± 1 b	2.87 ± 0.22 b	40.00 ± 0.00	1.47 ± 0.91 c	1473.27 ± 647.13 b	.	13.19 ± 0.70 b	11.74 ± 2.01 ab	3.30 ± 0.12
1.3	21 ± 8 a	2.80 ± 0.26 b	62.73 ± 26.11	5.11 ± 2.53 a	4369.33 ± 2164.65 a	.	15.18 ± 0.91 a	10.03 ± 0.94 b	3.30 ± 0.06
1.4	18 ± 7 ab	3.12 ± 0.14 a	60.83 ± 25.75	4.45 ± 2.57 ab	3804.88 ± 2199.02 a	.	15.49 ± 0.36 a	10.34 ± 0.49 b	3.38 ± 0.07
p value	* [f]	***	ns	***	**		***	***	ns
Vintage (V) Avg	17 ± 6 B [g]	3.00 ± 0.26 A	52.50 ± 21.90	3.38 ± 2.39 A	3075.15 ± 1978.63 A	.	14.32 ± 1.20 B	11.45 ± 2.32 A	3.32 ± 0.09 B
					2021				
1.1	21 ± 9 ab	2.59 ± 0.20 b	49.09 ± 20.23 b	2.34 ± 0.71 b	2134.69 ± 425.21 b	1.73 ± 0.83 b	15.02 ± 0.61 a	9.53 ± 1.08 b	3.62 ± 0.04 a
1.2	18 ± 2 b	2.58 ± 0.28 b	40.00 ± 0.00 b	0.98 ± 0.44 c	859.75 ± 385.96 c	0.95 ± 0.67 b	14.33 ± 0.37 b	10.00 ± 0.79 ab	3.58 ± 0.06 ab
1.3	25 ± 10 ab	2.72 ± 0.30 ab	65.00 ± 26.73 ab	2.45 ± 1.39 b	2159.21 ± 1289.23 b	8.85 ± 5.29 a	14.95 ± 0.73 ab	10.65 ± 1.61 ab	3.55 ± 0.05 b
1.4	32 ± 14 a	2.87 ± 0.22 a	90.00 ± 40.82 a	4.14 ± 1.46 a	3380.69 ± 1219.90 a	5.83 ± 3.22 a	14.74 ± 0.57 ab	10.71 ± 0.96 a	3.54 ± 0.05 b
p value	*	*	***	***	***	***	*	*	**
V Avg	24 ± 10 A	2.69 ± 0.27 B	59.70 ± 30.46	2.48 ± 1.55 B	2134.50 ± 1192.64 B	4.24 ± 4.36	14.76 ± 0.62 A	10.21 ± 1.21 B	3.57 ± 0.06 A
					T Avg over Both V				
1.1	18 ± 8 AB [h]	2.90 ± 0.36 AB	46.82 ± 17.56 BC	2.50 ± 1.40 B	2287.92 ± 754.51 BC	1.73 ± 0.83 B	14.25 ± 0.95 B	11.55 ± 3.03 A	3.46 ± 0.17
1.2	15 ± 2 B	2.73 ± 0.29 C	40.00 ± 0.00 C	1.22 ± 0.74 C	1220.64 ± 623.13 C	0.95 ± 0.65 B	13.76 ± 0.80 C	10.87 ± 1.74 AB	3.44 ± 0.17
1.3	23 ± 9 A	2.76 ± 0.28 BC	63.68 ± 25.65 AB	3.78 ± 2.41 A	3438.76 ± 2122.83 AB	8.85 ± 5.29 A	15.07 ± 0.82 A	10.34 ± 1.32 B	3.43 ± 0.14
1.4	23 ± 12 A	3.00 ± 0.22 A	71.58 ± 34.20 A	4.29 ± 2.05 A	3648.60 ± 1869.59 A	5.83 ± 3.22 A	15.12 ± 0.60 A	10.53 ± 0.77 AB	3.46 ± 0.10

Table 2. *Cont.*

Treatment (T) [a]	Berries per Cluster	Berry wt. (g)	Cluster wt. (g)	Yield (kg/vine)	Yield (kg/ha)	Ravaz Index (kg/kg)	TSS [b] (Brix)	TA [c] (g/L)	Juice pH
p value									
T	***	***	***	***	***	***	***	*	ns
V	***	***	ns	**	**	.	***	***	***
T × V	ns	***	ns	*	ns	.	***	***	**

[a] Treatment 1.1, early pruning; 1.2, early pruning + leaf removal; 1.3, normal pruning + leaf removal; 1.4, normal pruning (control). [b] TSS, total soluble solids. [c] TA, titratable acidity (primarily tartaric acid). [d] Different lowercase letters within columns and vintages indicate significant differences between treatments within those vintages. [e] ., missing data. [f] *, **, *** means significantly different at $p \leq 0.05, 0.01, 0.001$, respectively, or not significantly (ns) different. [g] Different capital letters within columns within each vintage average indicate significant differences between vintages. [h] Different capital letters within columns within each treatment average indicate significant differences between treatments in both vintages.

Variables that were affected by treatment include berries per cluster, cluster weight, yields, and Ravaz index (Table 2). The most apparent trend for these was that early pruning (T1.1, T1.2) had significantly lower values than normal pruning (T1.3, T1.4), including fewer berries per cluster, lower cluster weights, lower yields, and lower Ravaz index (Table 2). Normal pruning with leaf removal (T1.3) did not differ from normal pruning without leaf removal (T1.4) in any of these measured variables.

There was a significant difference between vintages in two of the variables measured: berries per cluster and yields (Table 2). While the yields in 2021 were lower than in 2020, the berries per cluster were higher (Table 2). Even though the number of berries in a cluster was lower in 2020, the berry weight was higher (Table 2), which may account for the higher yield of 2020.

3.2. Study 2

Weekly measurements of TSS and TA (Figure 5) showed some fluctuation over the GDD. There was, however, a strong negative correlation between the two variables ($p < 0.0001$, $r = -0.67$ (2020) and -0.85 (2021)), and as TSS increased, TA decreased. In 2020, TA decreased, plateaued, or even increased, and then continued to decrease. The slowing of TA degradation followed a week of high rainfall (14.5 cm) between 1622 and 1776 GDD. In 2021, there was an increase in TA following high amounts of rainfall (11.9 cm) between 1557 and 1710 GDD. Once the rainfall amounts lessened the following week (1.5 cm), the TA returned to its normal trend (Table 3 and Figure 5). In both vintages, the TSS increased in the beginning of the ripening period but the rate of increase slowed down and plateaued before harvest (Figure 5).

Table 3. Weekly phenological stage, rainfall, and average temperature and humidity in McNeill, MS starting from 'MidSouth' veraison to harvest for vines spaced 4.3 × 1.5 m in Study 2 (2020 and 2021).

2020					2021				
Week	**Phenological Stage of Vines** [a]	**Temperature (°C)** [b]	**Humidity (%)** [c]	**Rainfall (cm)** [b]	**Week**	**Phenological Stage of Vines**	**Temperature (°C)**	**Humidity (%)**	**Rainfall (cm)**
23–30 June	35	26.7	79.1	4.6					
30 June-9 July		27.3	80.8	14.5					
9–15 July	36	28.8	71.7	2.5	8–13 July	35	25.5	83.3	7.4
15–23 July		28.2	75.0	5.1	13–22 July	36	26.8	82.0	11.9
23–28 July	37	25.4	91.5	6.6	22–27 July	37	24.8	77.5	1.5
28 July–August 5		27.1	74.1	3.8	27 July–3 August	38	25.9	80.2	3.8
5–12 August	38	27.6	68.6	0					

[a] Stages adapted from modified Eichhorn-Lorenz system. [b] Data averaged from daily local measurements from Poplarville, MS (15 miles northeast of McNeill, MS). [c] Data averaged from daily local measurements from Stennis International Airport (33 miles southeast of McNeill, MS).

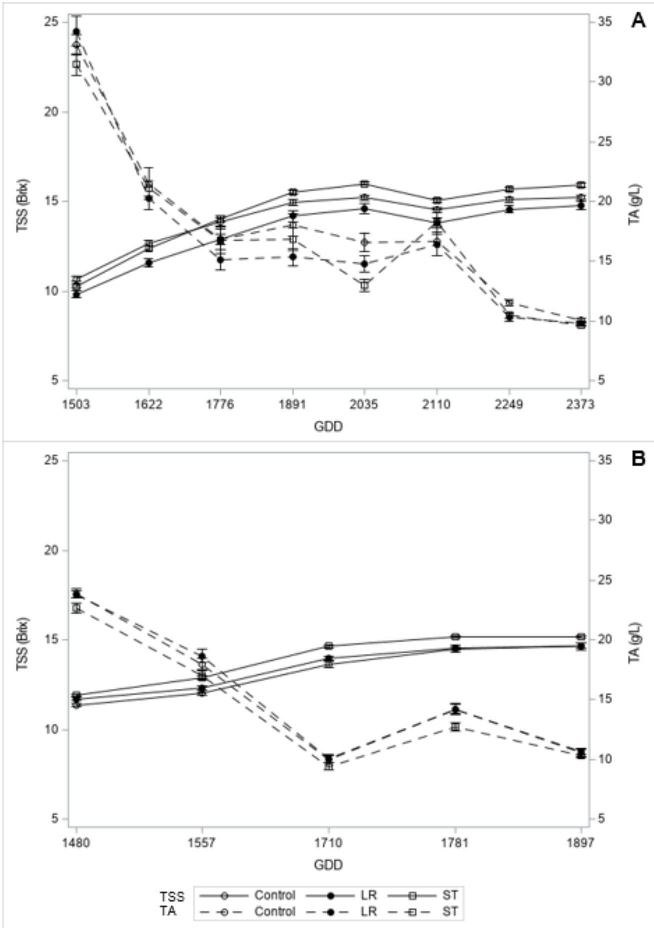

Figure 5. Weekly average 'MidSouth' total soluble solids (TSS) and titratable acidity (TA) for each treatment in Study 2 from veraison to harvest in 2020 (**A**) and 2021 (**B**) in McNeill, MS. LR, leaf removal; ST, shoot thinning; Control, no leaf removal or shoot thinning.

The only measured variables that differed by both treatment and vintage were yield per vine and juice pH. While yield per vine was highest for leaf removal vines (T2.1) in 2020, it was lowest for leaf removal vines in 2021, and juice pH appeared to be stable among each vintage (Table 4). Juice pH was lowest in leaf removal vines (T2.1) in 2020, and all treatments (T2.1, T2.2, T2.3) had higher pH values in 2021 than 2020 (Table 4).

Table 4. 'MidSouth' mean ± standard deviation yield components and grape composition for each treatment, vintage, and treatment and vintage interaction in Study 2 in McNeill, MS (2020 and 2021).

Treatment (T) [a]	Berries per Cluster	Berry wt. (g)	Cluster wt. (g)	Yield (kg/vine)	Yield (kg/ha)	Ravaz Index (kg/kg)	TSS [b] (Brix)	TA [c] (g/L)	Juice pH
					2020				
2.1	25 ± 12	2.89 ± 0.34 b [d]	75.26 ± 31.86	3.84 ± 2.37 a	6172.82 ± 3550.02 a	. [e]	14.79 ± 1.01 b	9.83 ± 0.68	3.34 ± 0.08 b
2.2	19 ± 10	3.06 ± 0.14 ab	60.00 ± 30.29	1.37 ± 0.96 b	2292.76 ± 1440.88 b	.	15.93 ± 0.59 a	9.68 ± 0.66	3.42 ± 0.10 a
2.3	22 ± 11	3.12 ± 0.16 a	71.57 ± 34.84	3.54 ± 2.96 a	5930.25 ± 4405.59 a	.	15.23 ± 0.58 b	10.08 ± 0.68	3.42 ± 0.07 a
p value	ns [f]	*	ns	**	**		***	ns	**
Vintage (V) Avg	22 ± 11	3.02 ± 0.25 A [g]	69.11 ± 32.49	2.92 ± 2.48 A	4843.36 ± 3777.05 A	.	15.32 ± 0.88 A	9.86 ± 0.68 B	3.39 ± 0.09 B

Table 4. *Cont.*

Treatment (T) [a]	Berries per Cluster	Berry wt. (g)	Cluster wt. (g)	Yield (kg/vine)	Yield (kg/ha)	Ravaz Index (kg/kg)	TSS [b] (Brix)	TA [c] (g/L)	Juice pH
					2021				
2.1	22 ± 8	2.62 ± 0.28	55.38 ± 24.02	1.67 ± 1.10 b	3303.75 ± 1525.56	10.72 ± 8.17 a	14.68 ± 0.64 b	10.69 ± 1.27	3.56 ± 0.08
2.2	25 ± 8	2.57 ± 0.23	61.43 ± 25.68	1.80 ± 0.68 ab	2620.23 ± 1118.62	3.95 ± 3.23 b	15.19 ± 0.29 a	10.31 ± 0.58	3.57 ± 0.05
2.3	26 ± 9	2.62 ± 0.32	63.33 ± 25.82	2.67 ± 1.44 a	3778.02 ± 2189.36	7.98 ± 9.55 ab	14.65 ± 0.85 b	10.56 ± 1.25	3.55 ± 0.05
p value	ns	ns	ns	*	ns	*	*	ns	ns
V Avg	24 ± 9	2.60 ± 0.28 B	60.24 ± 24.84	2.05 ± 1.19 B	3245.29 ± 1718.43 B	7.49 ± 7.86	14.84 ± 0.67 B	10.52 ± 1.07 A	3.56 ± 0.06 A
					T Avg over Both V				
2.1	24 ± 11	2.76 ± 0.34	67.19 ± 30.19	2.75 ± 2.13 A	5007.26 ± 3204.40 A [h]	10.72 ± 8.17 A	14.74 ± 0.84 B	10.26 ± 1.09	3.45 ± 0.14 B
2.2	22 ± 9	2.81 ± 0.31	60.63 ± 27.93	1.59 ± 0.85 B	2436.03 ± 1300.19 B	3.95 ± 3.23 B	15.56 ± 0.59 A	10.00 ± 0.69	3.49 ± 0.11 A
2.3	24 ± 11	2.87 ± 0.36	67.94 ± 31.02	3.10 ± 2.34 A	4980.73 ± 3714.43 A	7.98 ± 9.55 AB	14.94 ± 0.78 B	10.32 ± 1.02	3.48 ± 0.09 AB
p value									
T	ns	ns	ns	***	***	*	***	ns	*
V	ns	***	ns	**	*	.	***	***	***
T × V	ns	ns	ns	**	ns	.	ns	ns	*

[a] Treatment 2.1, leaf removal; 2.2, shoot thinning; 2.3, control (no leaf removal or shoot thinning). [b] TSS, total soluble solids. [c] TA, titratable acidity (primarily tartaric acid). [d] Different lowercase letters within columns and vintages indicate significant differences between treatments within those vintages. [e] ., missing data. [f] *, **, *** means significantly different at $p \leq 0.05$, 0.01, 0.001, respectively, or not significantly (ns) different. [g] Different capital letters within columns within each vintage average indicate significant differences between vintages. [h] Different capital letters within columns within each treatment average indicate significant differences between treatments in both vintages.

Variables that were affected by treatment included yields, Ravaz index, and TSS (Table 4). Shoot thinned vines (T2.2) had a lower Ravaz index than leaf removal vines (T2.1). They also had lower yields than other vines (T2.1, T2.3) but higher TSS (Table 4).

There were significant differences from year to year in several of the variables measured: berry weight, yields, TSS, and TA (Table 4). Berry weight, yields, and TSS were higher in 2020 than in 2021, but TA was lower.

4. Discussion

Both studies displayed some fluctuation in weekly TA over the GDD in both years (Figures 4 and 5). Increases in TA followed high amounts of rainfall in the previous week (Tables 1 and 3), and since tartaric acid has been shown to decrease with increased irrigation [37], it is possible that the high rainfall decreased the TA. Once the rainfall amounts returned to normal the following week, the TA returned to its normal trend (Tables 1 and 3 and Figures 4 and 5). A further decrease in TA occurred after or during a week of average high humidity (Tables 1 and 3), which again would result in more water surrounding the plant, leading to a decrease in the TA. Alternatively, it has been shown that at the beginning of berry ripening, malic acid contributes to respiration and the conversion of sugars in the berries but later contributes very little [38–40]. Thus, this use of malic acid could be responsible for the initial drop then plateau seen in weekly TA. Both TSS accumulation and TA degradation followed a similar pattern to that reported by Riesterer-Loper et al. [21].

The reduction in yield components in early pruned vines (T1.1, T1.2) agreed with VanderWeide et al. [12], who reported that early leaf removal limits inflorescence development due to a decrease in available sugars. 'MidSouth' likely already had limited carbohydrates available in its leaves from flowering to the young fruit stage, according to Jain et al. [41], so by removing these sugars in the leaves just before this decrease, the supply likely became even more limited, thus limiting the number of berries in a cluster, cluster weights, yields, Ravaz index, and subsequently measured carbohydrates in the berries. Similarly, in shoot thinned vines (T2.2), by removing the source of carbohydrates at fruit set when the supply was low, the amount likely became even more limited, thus limiting the resulting yield and Ravaz index [12,41], although it is likely this reduction in yield allowed for better TSS distribution among the fruit [25]. However, even with this better distribution, the TSS of shoot thinned vines (T2.2) still did not reach the recommended range for a varietal dry red wine grape, and while the other treatment vines (T2.1, T2.3) are considered well-balanced in relation to their Ravaz index, their yields are also relatively low, indicating a different pruning strategy may be needed [33].

In both studies, the differences in values from year to year are likely due to a difference in environmental conditions, such as higher amounts of rainfall during the ripening period in 2020 than in 2021 (Tables 1 and 3) [37,42]. In addition, the slightly higher humidity in 2021 (Tables 1 and 3) could have resulted in more disease that would have decreased the yield [24]. To determine a definite trend, additional testing that takes into account potential influencing variables, such as specific weather effects, should be conducted to determine if consistent improvements due to the treatments, such as the reduced TA reported by others after performing pre-bloom leaf removal, post fruit set leaf removal, pre-bloom shoot thinning, and/or post fruit set cluster thinning [14,19,21,23–26], are possible.

Due to the lack of improved harvest conditions and inconsistencies from year to year, early pruning treatments, with or without leaf removal (T1.1, T1.2), cannot be recommended for 'MidSouth'. Since the only measured variable that differed from normal pruning without leaf removal (T1.4) was berry weight in 2020 and yield in 2021, normal pruning with leaf removal at post-fruit set (T1.3) did not appear to have a substantial effect in the first study. Additionally, since 2020 juice pH and 2021 yield per vine were the only measured variables that differed from the control (T2.3) for leaf removal vines (T2.1), this treatment did not appear to have a large effect in the second study either. While the shoot thinning treatment (T2.2) had lower yields and Ravaz index and consistently higher TSS, the slightly higher TSS still does not bring 'MidSouth' near the standard winegrape quality of at least 22 Brix and would not justify the significant (51.3%) crop loss.

5. Conclusions

Due to the limited desired effects, early pruning with or without leaf removal at pre-bloom (T1.1, T1.2), normal pruning with leaf removal at post-fruit set (T1.3, T2.1), and shoot thinning at post-fruit set (T2.2) may not be an effective use of time and labor for improving the winegrape quality of 'MidSouth' in south Mississippi. Further research could determine if different pruning techniques or delaying pruning, leaf removal, or shoot thinning to a later growth stage might instead produce a more desirable effect of improving 'MidSouth' quality for varietal red wine use, but for now it is recommended that south Mississippi growers of 'MidSouth' continue to apply normal pruning practices without these canopy management techniques. With this lack of improved fruit quality, producers of 'MidSouth' wine may look to perform alternative winemaking techniques, such as malolactic fermentation or blending with higher total soluble solid to titratable acid ratio grape cultivars or other small fruits to achieve a more desirable wine composition.

Author Contributions: H.N.W. and E.T.S. conceived and designed the research. H.N.W. carried out the study and analyzed the data. Y.Z. and S.K.C.C. provided lab space, materials, and assisted with data collection. H.N.W. prepared the original draft. E.T.S., S.K.C.C. and Y.Z. reviewed and edited the manuscript. All authors have read and agreed to the published version of the manuscript.

Funding: The project was founded through a Specific Cooperative Agreement between Mississippi State University and USDA-ARS, supported by the Mississippi Agricultural, Forestry and Experiment Station and Mississippi State University Extension Service. This material is based upon work that is supported by the National Institute of Food and Agriculture, U.S. Department of Agriculture, Hatch project 1014723, MIS-149192, and in part by Hatch project MIS-081710 and USDA-ARS project no. 0500-00031-001-00D, titled 'Mississippi Center for Food Safety and Post-Harvest Technology'.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: We thank the crew at the MAFES South MS Branch Experiment Station for assisting in pruning and harvest activities and the MAFES Experimental Seafood Processing Lab for providing lab space and technical support. We also thank Guihong Bi, Christine Coker, and Rebecca Melanson for their review and contributions to this work.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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