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Precipitation Nutrient Inputs in Semiarid Environments

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ABSTRACT

Seasonal and spatial variations in precipitation nutrient inputs were suggested by differences in storm type and air mass origin into southeastern Arizona. Wet precipitation NO_3-N, NH_4-N, PO_4-P, and K inputs were collected at seven sites to determine seasonal and spatial variations in nutrient inputs. Total nutrient inputs and concentrations in summer precipitation were significantly greater than in winter precipitation. Higher summer total inputs and concentrations were attributed to storm type and air mass origin rather than precipitation amount, as summer precipitation accounted for 56% of the precipitation and 79, 69, 66, and 73% of the NO_3-N, NH_4-N, PO_4-P, and K, respectively. Spatial variability in nutrient inputs was limited to specific nutrients, seasons, and sites and attributed to precipitation variability and localized sources. Generally, the air masses and storm types that produced seasonal differences in nutrient inputs and concentrations affected all sites uniformly.

IN SOUTHEASTERN Arizona precipitation is bimodally distributed, with 60 to 70% in summer thunderstorms and 30 to 40% winter frontal storms (Osborn and Simanton, 1987). Summer thunderstorm air masses originate in the tropics and move either across the Gulf of Mexico or Gulf of California into southeastern Arizona (Osborn, 1981). Winter frontal storm air masses originate in the Pacific Ocean and move across California into Arizona. Summer storms produce high-intensity rains that are short in duration and limited in areal extent (Osborn, 1968; Osborn, 1983). Winter storms generally produce low-intensity, long duration storms that travel considerable distances and cover large areas.

The different storm types and air mass originations suggest that important seasonal and spatial differences should exist in precipitation inputs of essential plant nutrients. Knowledge of seasonal and spatial variations and the magnitude of nutrient inputs are important for understanding plant growth and nutrient cycling. The objective of this study was to evaluate the seasonal and spatial distribution of N, P, and K precipitation inputs in southeastern Arizona.

MATERIALS AND METHODS

Study Area

In 1983, seven precipitation collector sites were established in southeastern Arizona (Fig. 1). Site locations were selected to represent a range of environments. At the Walnut Gulch Experimental Watershed (WGEW) near Tombstone, AZ, samples were collected for 4 yr at four subwatershed sites numbered 104, 112, 121, and 124. Elevation at these sites ranged from 1360 to 1485 m and distance between sites ranged from 2.4 to 10.5 km. Vegetation at site 104 was predominantly brush with erosion pavement protecting the soil surface, whereas at sites 112 and 124 vegetation was predominately grass. Collector site 121 was next to a small rural development and many residences maintained farm animals. Other collector sites were at the Aridland Watershed Management Research Unit (AWM), Tucson, AZ (elev. 710 m), Chiricahua National Monument (CNM) Visitors Center (elev. 1615 m), and Phelps Dodge Smelter (PDS) Douglas, AZ (elev. 1231 m). Vegetation was oak (*Quercus* spp.), pine (*Pinus* spp.), and grass at CNM, brush at PDS, and a wide variety of introduced vegetation at AWM. The AWM site was within 0.3 km of the University of Arizona Dairy Research Farm. Samples were collected at these sites for 5 yr. The 30-yr average annual precipitation at the closest National Oceanic and Atmospheric Administration (NOAA) station for WGEW, AWM, CNM, and PDS was 325, 294, 453, and 308 mm, respectively.

Sample Collection and Analysis

Nutrient input was intended to include only the nutrient that came from outside the collection site. Frequent wind storms in semiarid environments, however, deposit windblown particles from local sources in open bulk and dry collectors. Hence, wet precipitation collectors only open during a precipitation event were used to reduce locally derived inputs.

Precipitation was collected in 20.3-cm diam. automatic opening collectors (Schreiber et al., 1978), modified to operate on a 12-v battery and solar panel. Moisture on the sensor grid completed an electronic circuit that opened the collector lid when a storm started and closed it when the storm ended to prevent sample evaporation. The sample was stored in a disposable plastic bag inside the collector and transferred to a 125-mL sample bottle for shipment to the laboratory. Samples were collected and sent to the laboratory for preservation within 2 to 4 d. Four-milliliter subsamples for NO_3-N, NH_4-N, PO_4-P analysis were frozen and K subsamples preserved with La-HCl and refrigeration (Perkin-Elmer, 1976). Nitrate-N, NH_4-N, and PO_4-P concentrations were determined with a Technicon AutoAnalyzer II using industrial methods 100-70W, 98-70W/A, and 155-71W, respectively. Potassium samples were analyzed on a Perkin-Elmer 403 atomic absorption spectrophotometer. The samples were analyzed within 30 d of collection. Some samples represent more than one precipitation event because samples could not be collected before the next event. Precipitation quantity was determined volumetrically at each site.

Total input was calculated for each nutrient by multiplying concentration by precipitation amount. Input was summed for the winter (Oct.–May) and summer (June–Sept.) seasons and volume-weighted mean concentrations were calculated for seasons by dividing total nutrient input by total precipitation volume. Volume-weighted mean concentrations were used because arithmetic mean concentrations are artificially elevated by small precipitation events with high concentrations.

An analysis of variance model used sites and seasons as fixed effects with years as random effects and seasons as repeated measures. A 0.05 probability level was the criteria for accepting or rejecting the null hypotheses. Variance homogeneity between seasons was tested with an *F* ratio. Site × season interactions were tested before sites were pooled for seasonal separations. Tukey's studentized range (HSD) test was used to separate means. Overlap of 95% confidence intervals were used to separate seasons with significantly different variances and nonsignificant season × site interaction. Nonoverlap of 95% confidence interval was considered significantly different. Site × season interactions were tested

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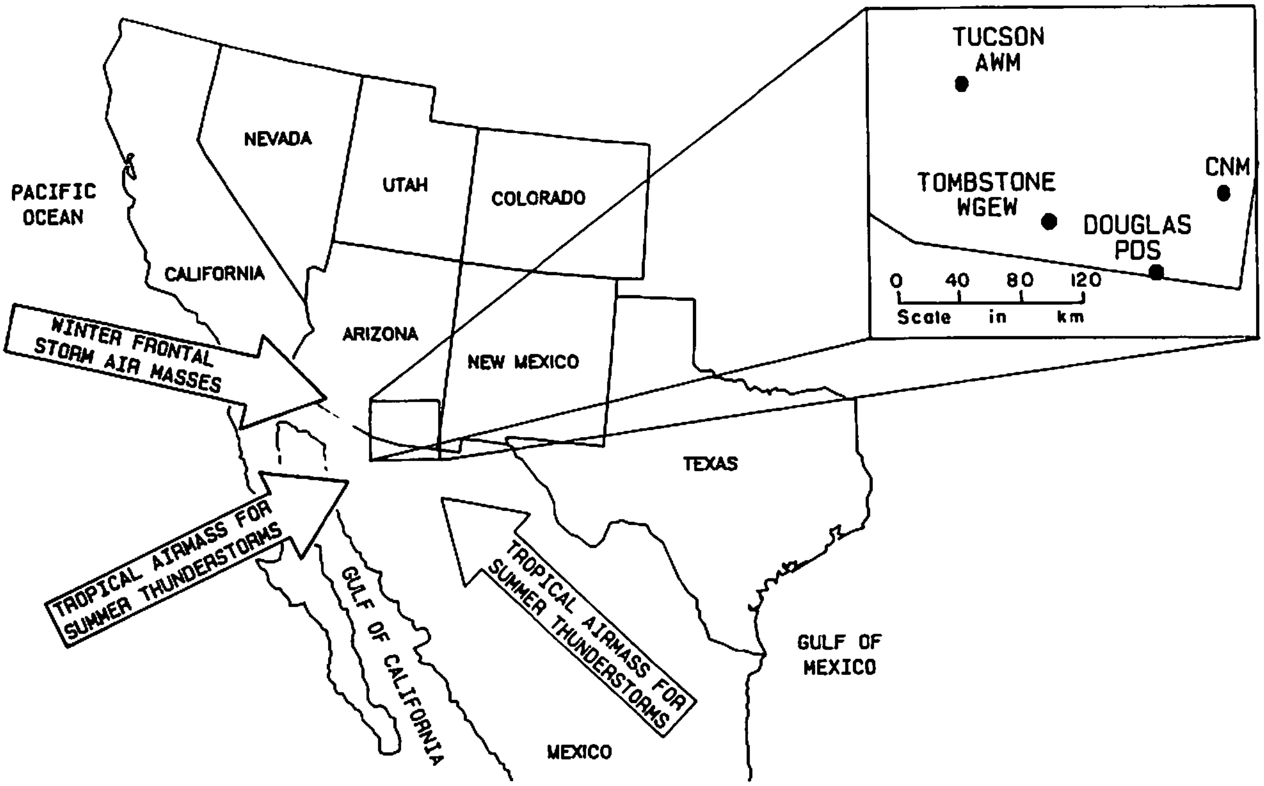

Fig. 1. Collector site locations and seasonal air mass origins. Tombstone WGEW includes four collector sites.

before seasons were pooled for site separations. For site separations, seasons were pooled when seasonal variances and site × season interactions were nonsignificant. Site mean separations were made within season for significantly different variances between seasons.

RESULTS

Precipitation

Total yearly precipitation between 1983 and 1987 was above the 30-yr mean (NOAA) at most sites, whereas precipitation at the AWM site was below average for 3 of the 5 yr (Table 1). The AWM site is north of all other sites and received less tropical summer moisture from the south (Fig. 1). The CNM site receives more winter and overall precipitation because its elevation is higher and it is affected by orographic lifting from the Chiricahua Mountains. Summer precipitation was 60 to 62% of the total at the WGEW sites. Extreme spatial variability in summer precipitation reported by Osborn and Simanton (1987) was observed at WGEW. For example, in 1983 site 124 received only 65% of the precipitation of site 121, which was located 2.5 km away.

Table 1. Precipitation means by site.

Site	Season† Winter	Summer	Total	NOAA‡ 30-yr avg.
	mm			
104	200(29)§	297(38)	498(54)	325
112	174(62)	258(60)	433(65)	325
121	205(41)	311(99)	523(146)	325
124	137(32)	222(42)	358(66)	325
AWM	186(83)	138(104)	325(115)	294
CNM	292(56)	240(62)	532(107)	453
PDS	138(35)	273(38)	412(66)	308

† Winter = (Oct.-May), Summer = (June-Sept).
‡ 30-yr averages as measured at nearest NOAA climatological station.
§ Values in parentheses are SD of the mean.

Total Nutrient Input

Total annual and seasonal nutrient means are presented in Table 2. Annual NO_3-N, NH_4-N, PO_4-P, and K inputs ranged from 0.45 to 1.35, 0.41 to 1.95, 0.003 to 0.12, and 0.22 to 4.15 kg/ha, respectively, among the sites. These values were outside the 95% confidence intervals, indicating that for a particular year and site there was considerable variability in incoming nutrient. Young et al. (1988) reported higher annual NO_3-N and lower NH_4-N inputs to a site in southern Arizona, but the sum of N from these two sources was similar to values in Table 2.

Season × site interaction was not significant for total nutrient, but seasonal variances were significantly different and prevented seasonal evaluation with analysis of variance. Hence, 95% confidence intervals were used to separate seasonal differences for total nutrients. The intervals did not overlap. Therefore, sea-

Table 2. Total nutrient input means by season combining sites.

Nutrient	Season† Winter	Summer	Annual
	kg/ha		
NO_3-N	0.16 (0.02)‡	0.61 (0.08)	0.77 (0.09)
NH_4-N	0.38 (0.08)	0.84 (0.14)	1.20 (0.17)
PO_4-P	0.019 (0.006)	0.037 (0.010)	0.055 (0.012)
K	0.35 (0.10)	0.94 (0.16)	1.28 (0.20)

† Winter = (Oct.—May), Summer = (June-Sept).
‡ Values in parentheses are 95% confidence intervals.

Table 3. Total nutrient input means by site.

Nutrient	104	112	121	124	AWM	CNM	PDS
	kg/ha						
			Winter†				
NO_3-N	0.15ab*	0.10b	0.11b	0.11b	0.23ab	0.26a	0.15ab
NH_4-N	0.27a	0.42a	0.62a	0.14a	0.52a	0.43a	0.22a
PO_4-P	0.024a	0.013a	0.037a	0.021a	0.012a	0.022a	0.008a
K	0.42a	0.27a	0.46a	0.27a	0.42a	0.30a	0.35a
			Summer				
NO_3-N	0.77a	0.68a	0.60a	0.56a	0.45a	0.57a	0.69a
NH_4-N	1.11a	0.76a	1.37a	0.83a	0.66a	0.56a	0.80a
PO_4-P	0.042a	0.045a	0.031a	0.050a	0.033a	0.045a	0.016a
K	1.36ab	1.17abc	1.78a	0.95abc	0.30c	0.66bc	0.81bc

* Values within each row followed by the same letter are not significantly different at $P = 0.05$, Tukey's HSD.

† Winter = (Oct.–May), Summer = (June–Sept).

sonal nutrient differences were considered significantly different with more nutrient input in summer precipitation than winter (Table 2).

Significant differences in seasonal variances required sites be separated by season for total nutrient inputs (Table 3). Ammonium-N and PO_4-P inputs were not different among sites. Nitrate-N inputs were similar among sites in the summer, but sites 112, 121, and 124 were different than CNM during winter. Potassium inputs were similar among sites in winter. In summer, however, Site 121 was different than AWM, CNM, and PDS; and Site 104 was different than AWM. Ammonium-N and PO_4-P showed no spatial differences in inputs, whereas NO_3-N and K spatial variations were small. This would indicate reasonably uniform nutrient reception among sites.

Volume-Weighted Mean Concentrations

Volume-weighted mean seasonal variances and season × site interactions were similar for NO_3-N and NH_4-N. Therefore, seasonal concentrations were separated by analysis of variance. Nitrate-N and NH_4-N concentrations were significantly higher in the summer (Table 4). Phosphate-P and K season × site interactions were similar, whereas seasonal variances were not. Hence, 95% confidence intervals were used for seasonal concentration separations. The confidence intervals did not overlap. Therefore, the higher summer concentrations were considered significant. Higher summer volume-weighted mean nutrient concentrations indicated a seasonal variation in the precipitation concentrations.

Table 4. Volume-weighted mean concentrations by season combining sites.

Nutrient	Winter	Summer
	Season†	
	mg/L	
NO_3-N	0.09a*	0.27b
NH_4-N	0.20a	0.39b
PO_4-P	0.010 (0.003)‡	0.019 (0.006)
K	0.20 (0.06)	0.40 (0.09)

* Values within each row followed by the same letter are not significantly different at $P = 0.05$, Tukey's HSD.

† Winter = (Oct.–May), Summer = (June–Sept).

‡ Values in parentheses are 95% confidence intervals.

Volume-weighted mean site concentrations were separated by analysis of variance for NO_3-N and NH_4-N (Table 5). Nitrate-N concentrations for sites 121 and AWM were the only two that were different. Site 121 NH_4-N concentration was different than all other sites except AWM; and AWM was distinguishable from 124 and CNM. Dissimilar seasonal variances required PO_4-P and K site concentrations be separated within season. There were no significant differences within season; hence, site concentrations for PO_4-P and K were considered similar. This indicated there was no detectable spatial variability in site concentrations for PO_4-P and K and limited variability for NO_3-N and NH_4-N.

DISCUSSION

The seasonal distinctions found in total nutrient inputs (Table 2) had to be caused by differences in precipitation amount and precipitation nutrient concentration. Precipitation nutrient concentration is influenced by air mass nutrient concentration and storm type. Hence, greater total nutrient in summer precipitation was attributed to a combination of increased summer precipitation, air mass nutrient content, and storm type.

Greater summer nutrient input, however, cannot be attributed solely to summer precipitation as more nutrient input was found in proportion to increased precipitation. Average summer site precipitation accounted for 56% of the precipitation and 79, 69, 66, and 73% of the NO_3-N, NH_4-N, PO_4-P, and K incoming nutrient, respectively (Tables 1 and 2). The higher summer precipitation concentrations were concluded to have produced most of the increase in total summer nutrient inputs (Table 2).

Precipitation nutrient concentrations are affected by air mass nutrient concentration and storm type. Air mass nutrient concentration was not determinable, but summer tropical air masses from the south were theorized to contain more nutrient than winter air masses from the west (Fig. 1). Higher tropical air mass nutrient concentrations would account for the observed higher summer precipitation nutrient concentrations, irrespective of storm type effect (Table 4). Storm type can produce higher summer precipitation nutrient concentrations with identical concentrations initially in the two air masses. In northern California, Cl ion concentration in wet precipitation has been shown to decrease exponentially with distance in from the Pacific Ocean (McColl et al., 1982). As winter frontal storm air masses from the Pacific Ocean move eastward, elements were depleted by precipitation washout. Hence, frontal storm air mass that reach south-

Table 5. Volume-weighted mean concentrations by site combining seasons.

Nutrient	104	112	121	124	AWM	CNM	PDS
				Site			
				mg/L			
NO_3-N	0.17ab*	0.16ab	0.11b	0.16ab	0.25a	0.17ab	0.20ab
NH_4-N	0.25bc	0.25bc	0.51a	0.22c	0.43ab	0.19c	0.24bc

* Values within each row followed by the same letter are not significantly different at $P = 0.05$, Tukey's HSD.

eastern Arizona have lowered precipitation nutrient concentrations. Conversely, summer thunderstorms from tropical air masses have limited mobility, thus depositing more nutrient in smaller areas and producing higher nutrient concentrations. Both air mass nutrient concentration and storm type contributed to greater summer precipitation nutrient concentrations, but the magnitude and importance of each could not be determined.

Spatial variability was indicated by differences in sites for total nutrient inputs and concentrations (Tables 3 and 5). The spatial variability was limited to specific nutrients, seasons, and sites and attributed to precipitation variability and localized nutrient sources. Local anthropogenic emission sources of NO_x from automobiles and NH_3 from manure near the AWM site contributed to increased, but not significantly different, winter total nutrient inputs and concentrations. Kennedy et al. (1979) found elevated NO_3-N levels in urban precipitation compared to rural and believed it to be derived in part from anthropogenic sources. Summer nutrient inputs at the AWM site of NO_3-N and NH_4-N were not elevated due to low precipitation (Table 1), whereas volume-weighted mean concentrations were, as they are less dependent on precipitation amount. The NH_3 manure emissions near site 121 and highest summer precipitation increased NH_4-N nutrient input and concentration. Elevated summer total K inputs at sites 104 and 121 were attributed to localized dust washed into the collector from the easily wind-erodible soils.

The observed spatial variability did not indicate a separate nutrient source from outside the study area inputing to any group or single site. The air masses and storm types that produced seasonal differences in nutrient inputs and concentrations affected all the sites uniformly, once the localized input sources and precipitation variability were evaluated. Kelly (1984) also concluded, based on bulk precipitation, that elemental inputs appear to be regional rather than local in origin.

The total precipitation nutrients were low when compared with many locations (Wilson and Mohnen, 1982; Verry, 1983; Kelly, 1984; Young et al., 1988), and probably were related to low annual precipitation and significant distances from industrial emission. But their importance in nutrient cycling and plant growth might be significant due to their availability and timing. Cox (1985) determined aboveground biomass and N quantities in a big sacaton (*Sporobolus wrightii*) grassland community in southeastern Arizona. Total N in the standing biomass ranged from 11 kg/ha in February to 33 kg/ha in August. In this study total NO_3-N and NH_4-N input in wet precipitation averaged 1.97 kg/ha among sites (Table 2). The 1.97 kg/ha represents 6 and 18% of the total N in the standing biomass for summer and winter, respectively. The remaining N for plant growth must be obtained from less available soil sources. The importance of the readily available atmospheric nutrients to plant growth should not be underestimated. Plant growth takes place primarily in the summer months and this corresponds to majority precipitation nutrient input (Table 2).

Nutrient losses in semiarid environments may be lower than the precipitation inputs allowing for accumulations. Nutrient accumulation in biomass is an important aspect of nutrient cycling. Studies in other environments have shown that inputs of soluble N in precipitation is greater than that lost in surface runoff waters (Schuman and Burwell, 1974; Olness et al., 1975; Schreiber et al., 1976; Schlesinger et al., 1982). Surface runoff losses are presently being determined on WGEW and will be analyzed in conjunction with precipitation nutrient inputs to evaluate nutrient accumulations.

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